

EFFECTS OF DIFFERENT TYPES OF
LIGHTING ON HUMAN
PERFORMANCE

A THESIS
SUBMITTED TO THE DEPARTMENT OF
INTERIOR ARCHITECTURE AND ENVIRONMENTAL DESIGN
AND THE INSTITUTE OF FINE ARTS
OF BILKENT UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF FINE ARTS

By
Azra Üstünlü
May, 1998

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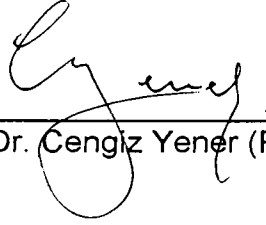
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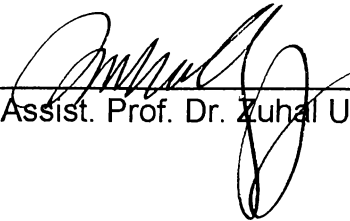
I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Fine Arts.


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ABSTRACT

EFFECTS OF DIFFERENT TYPES OF LIGHTING ON HUMAN PERFORMANCE

Kaan Ödemiş

M. F. A. In Interior Architecture and Environmental Design

Supervisor: Assoc. Prof. Dr. Cengiz Yener

May, 1998

This thesis discusses the effects of different types of lighting on human performance in working environments. Different interior lighting types may be effective on improving performance or on the contrary hindering the performance. Another point that is considered is psychological, physiological and visual effects of different lighting types on workers which may hinder or improve performance. This work is trying to find out the proper working conditions for good performance in relation to lighting. Also human performance models, visual performance and relations with lighting and conditions for improving performance are discussed.

Keywords: Lighting conditions, Lighting types, Human performance, Visual performance.

ÖZET

DEĞİŞİK IŞIKLANDIRMA TİPLERİNİN İNSAN PERFORMANSINA ETKİSİ

Kaan Ödemiş

İç Mimarlık ve Çevre Tasarımı Bölümü

Yüksek Lisans

Tez Yöneticisi: Doç. Dr. Cengiz Yener

Mayıs, 1998

Bu çalışmada değişik ışıklandırma tiplerinin büro mekanlarında, insan performansı üzerinde olan etkisi sorgulanmıştır. Çalışmanın sonucu olarak bazı değişik ışıklandırma tiplerinin insan performansı üzerinde artırıcı veya engelleyici etkisinin olup olmadığı ortaya konmaya çalışılmıştır. Özellikle ofis çalışanları bütün zamanlarını iç mekanlarda geçirdikleri için, ışıklandırma tiplerinin psikolojik, fizyolojik ve görsel açıdan performanslarını etkileyip etkilemediği incelenmiştir. Bu çalışma, yeterli performans için ışıklandırma açısından uygun çalışma ortamlarını araştırmaktadır. Ayrıca insan performans modelleri, görsel performans, ışıklandırma-performans ilişkileri ve performans iyileştirme durumları da tartışılmıştır.

Anahtar Sözcükler: Işıklandırma yöntemleri, Işıklandırma tipleri, İnsan performansı, görsel performans.

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And Muge, you catch me at the just end of the thesis but I will never forget your support and patience.

I dedicate this work to my family.

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1. INTRODUCTION

We perform mentally and react emotionally within settings that are artificial, in contrast to environments where we have evolved and developed our internal faculties. There are occasions in between when people visit and enjoy real natural settings. The point is, however, that for most of our lives we spend our time in man-made settings that entail, and expose us to, different physical indoor variables, one such is artificial light (Knez, 39).

Lighting is an essential ingredient of work environments. Not only it influences an individual's perception of work related tasks, but it also affects their general emotional and motivational state and health. Many other factors affect performance, but an important factor is lighting that has influence on human performance in the work environment (Katzev, 759).

Lighting is important for people. In a research done in 1979, respondents in Louis Harris poll of office workers, "good lighting" was cited as a feature that makes an office comfortable more than any other feature, such as lighting 85% versus 73% for the second-ranked feature "comfortable chair" (Veitch & Gifford, 448). In another research, Veitch, Hine, and Gifford in 1993 surveyed undergraduate students and found strong agreement that lighting is important for studying effectiveness, mood, and well-being (Veitch & Gifford, 463).

This thesis aims to study the effects of different general lighting systems on human performance, in terms of accuracy and speed of performance, only by changing the lighting arrangements. Different lighting types affect people's psychology and well-being. At the same time, different lighting systems affect people's performance especially in working environments. Visibility or perception of a task by people change according to different arrangements of lighting systems.

The lighting systems that have been examined here are cove lighting, wall washing and uplighting. These lighting types are explained in the text, in the fourth chapter. In daily activities, visual acuity and visual performance influence human performance in general. Senses are very effective on human performance like arousal, fatigue, etc. The speed of performance and accuracy of occupants under different lighting arrangements and under same level of illuminance were tested in the experimental study. Also the relation of age, sex differences and eye defects are searched in experiment withing same settings.

2. LIGHTING, HUMAN PERFORMANCE AND VISUAL PERFORMANCE

2.1. Defining Human Performance

As human beings, we are always performing in several systems exposing similar behavior. 'Somebody is doing something, in someplace' concept is valid for each daily activity. Writing, reading, watching, driving in a traffic jam, etc. are some examples of these different daily activities. As mentioned above, in each case there is somebody doing something, in someplace. A human is performing some activity in some context which is the main concept of human to be a living (Bailey, 4).

As Bailey (14) said human beings, that always perform in their daily life are the most complex of all components in any system. Human performance is often degraded because of poor design decisions pertaining to the activity being performed including the tools being used or even the context in which an activity is performed. Also physical, social environments and psychological effects have countable effects on improving and degrading human performance (Sundstrom, 84). Other factors such as motivation, stress, fatigue, etc., play an important role on human performance and must be taken into account (McNelis, 190).

Then Bailey defined performance "a pattern of actions carried out to satisfy an objective according to some standard. The actions may include observable behavior or not observable intellectual processing (e.g., problem solving, decision making, planning, reasoning)." Also another thing that

Bailey (4) stated, things change when people perform something. Bailey (5) stressed about the standards for measuring performance and pointed out that without these standards there is no way to measure the performance, but only the suggestions for improvement can be made. These standards and measurements for human performance are discussed in chapter 4.

2.2. Human Performance Model

There are some human performance models which were developed by some researchers and these models help for better understanding of human performance. Bailey (16) points out a type of human performance model in his book. This performance model requires an understanding of the *human*, the *activity* being performed, and the *context* in which it is performed. According to Bailey (16) this model is enough to serve as a model for many performance situations in general. See Figure 2.1.

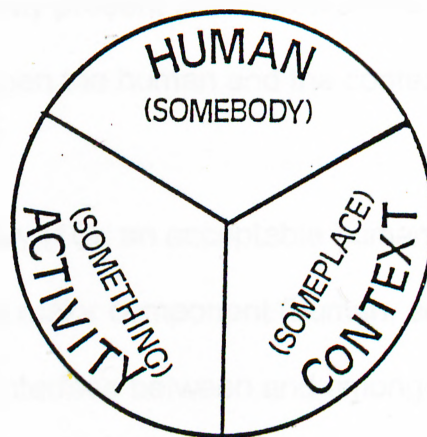


Fig. 2.1. Human Performance Model.

Bailey, Robert W. 1982. Human Performance Engineering. New Jersey: Pertince Hall, Inc. 16.

Sometimes, human beings seek to attain *super* performance which means near perfect performance that the activity requires. In some cases the activity requires *optimal* performance or *acceptable* level of human performance. But we must always avoid of the *degraded* performance. Whatever it is, a super, optimal or acceptable level of human performance, the following elements must taken into account:

- * The general state or condition of the human
- * The activity, including any required tools or equipment
- * The context in which an activity is performed (Bailey, 17).

If we want to simplify these three elements, we can call them in a phrase, *somebody does something in someplace*. A good understanding of these three elements is not sufficient to predict human performance because of the critical interactions between these elements. Interactions between activity and the context may present some problems and in addition to these, interactions between the human and the context may also vary (Bailey, 16).

According to Bailey (18), an acceptable human performance depends on the adequacy of each major component (human, activity, context) and the adequacy of the interface between and among major components. In all performance situations, these three elements should be considered separately or in combination to help for reaching the desired level of human performance. Each of these elements is briefly discussed in the following sections.

2.2.1. The Human

Bailey (18-19) explains the human as the most complex element of these three, and the most important one of all. Human performance can be affected positively and negatively by different conditions of human, without considering the activity and context.

The main considerations of the human element are the sensors, brain (cognitive) processing, and responders. These considerations include:

- * sensors ⇒ good vision and including adequate hearing
- * brain ⇒ ability to think reason and make decisions
- * responders ⇒ arms, fingers, mouth that function properly (Bailey, 19)

Also a similar approach to this subject is pointed out by McNelis (190). He states like Bailey, “the entire process of human performance may be considered as three step activity: seeing, thinking, and responding”. Again McNelis (190) shares the same ideas with Bailey that each step has complex relationships among many factors. According to him, the visual aspect of this relation is the most difficult part. Visual input must be adequate to complete the thinking process in a high degree of confidence. During the evaluation process of the inputs, human being uses prior instructions, previous experiences and other stored mental knowledge. Then this process will go in a proper course of action. If human have poor or inadequate visual input, it will limit the thinking process and at the same time limit the action of

the human. In the last step visual activity takes place to guide the human in proper courses of action.

2.2.2. The Activity

The second primal consideration in understanding human performance is the activity performed. The activity, in other words, what the human do is important for performance. Because every activity has different conditions, specialties, concepts, etc., and it results in different human performance levels. Interactions and stimuli from environment will be different for the human in different activities that the optimum performance or adequate performance level should be provided (Bailey, 20-21).

2.2.3. The Context

According to Bailey (22), the context is the last consideration in this model. It is the context in which a human performs a particular activity. Bailey (22) brings two different considerations, the physical context and the social context. The physical context includes the effects of lighting, temperature, noise, etc., on human performance. The social context that may affects human performance includes the effects of other people, crowding, isolation, etc.

The contexts are varied in which people live, work and spend their leisure hours. These environments are mostly not natural, predominantly human-made like light level, temperature, etc. The context in which people work can

enhance or degrade their performance. It does not always control the performance but only extreme environments can do this. Here human-environment interaction is very important. This is a chain event, that is first the environment impacts on people, and then people make changes either to lessen the effects of the environment or to alter the environment. The most important point is to provide much user control over a work environment as possible (Bailey, 484).

Another case about this subject is the social context. This is about the effects of people on other people. Most people are influenced by the social pressure, competitive forces, presence and absence of others in the work place. Some keywords about this, for ensuring the acceptable level of performance, can be; privacy, personal space, crowding and density, territoriality and isolation (Bailey, 488).

2.3. Lighting and Human Performance

Lighting is a very essential ingredient of the work environments, and it is very critical for jobs that deal with visual discrimination of small details (Sundstrom, 84). The physical performance is affected by internal and external factors. Lighting is an external factor which plays an important role on increasing or degrading human performance such as poor lighting or too high intensity of lighting is undesirable. As Rasyid and Siswanto (323) explained in their performance and productivity study, "increasing light intensity from 100 lux to 500 lux results in an increase in productivity of 9.5

per cent” clarifies the idea about the close relation between performance and lighting (Rasyid and Siswanto, 320).

According to Boyce (222), lighting can effect the performance of work in two ways:

It can do so directly by changing the physical characteristics of the task and/or by varying the operating state of the visual system; the combined effect being to alter the visibility of the task. However, lighting can also influence the performance of work indirectly (i.e., without altering the visibility of the task). This indirect influence of lighting can occur either because of a change in the general level of activation of the individual, or because lighting affects mood and hence motivation.

From the results of the study conducted by Crouch and Nimran (219), the occupants are unconscious about the effects of lighting on work performance.

Numerous previous studies have examined the relationships between the amount of illumination and performance. Most of the works showed that there is a parallel relationship between amount of illumination and performance (Eastman Kodak Company, 225). This point is explained briefly in the next section.

Another fact about the amount of illumination which was pointed out by Eastman Kodak Company, Human Factors Section Health Safety and Human Factors Laboratory (226), is energy cost problem. Increase in the amount of illumination is ended up with the increase in cost. But we may say that higher levels of illumination increase the performance of workers and also the productivity. Then we can assume that this may cause an reduction in labor costs more than the costs of the additional lighting. Energy conservation needs reduction in lighting levels. If we are going to apply this procedures, the main concern should be to find out how to increase performance while decreasing, or at least not increasing, the amount of energy used for lighting.

2.3.1. Developments on Lighting, Human Performance Relationship

Researches on the influences of lighting on human performance have begun on the intensity of light and visibility of details. The other studies were about the quality and distribution of lighting. The earliest studies were conducted in factories about lighting and performance and it was followed by laboratory studies on visual performance. Recent studies involved field studies in which researchers tried to use real working personnel in actual work places (Sundstrom, 87).

2.3.1.1. Intensity of Lighting

The first studies about effects of intensity of lighting on human performance have begun with some field experiments in the factories at the beginning of

the 1920's. But in these years, like Elton and Weston did, the researches were about daylight effects in the interiors of factories. The most important result of all the researches was the importance of light on the critical visual discrimination of details, increased intensity of lighting and improved performance (Sundstrom, 88).

Sundstrom (89) continued to make explanations about the laboratory studies which took place in Harvard University in the same year with the field studies in 1920's. A tapping test and a test of reaction time were done. The results of this study brought that bright light helps for the faster work but may create arousal in terms of visibility of details. These results were largely ignored by the later researches.

After these studies, Hawthorne studies was held. The Western Electric Company initiated a research project in between years 1924 and 1932, sponsored by National Research Council of the National Academy of Sciences (Huczynsky and Buchanan, 156). This project is about "the relation of quality and quantity of illumination to efficiency in industry".

The experiments on illumination were to give different conditions of illumination for three different departments (Sundstrom, 89). The workers were divided into two groups. But the results obtained were confusing. They discovered that in no case was the production output obtained in proportion to the lighting provided. Product even increased when the intensity of light

declined (Huczynsky and Buchanan, 157). The result was disappointing because two departments gave no normal outputs. This is because of the motivating effect of being observed, which is still now called as “Hawthorne Effect”. It is used to describe the unintended influence of researchers on the performance of people under observation. After these researches, two more experiments were done by the Hawthorne researchers. Again, the results were not as expected. (Sundstrom, 89).

The results were discouraged researchers but the studies made researchers to look at psychology of the work place in a different manner. A decade later the Hawthorne studies, the importance of these studies is to divert the researchers more seriously into the influences of physical environment on performance (Sundstrom, 89).

According to Sundstrom (89), the analytic approach was firstly defined by Weston who was a British researcher used a laboratory task for discrimination of visual stimuli, called “Landolt Rings” (small circles, each with a small gap on one side), in 1945. This approach is for visual difficulty of the tasks that in terms of size of detail and amount of contrast, determined with appropriate brightness of lighting. With this approach Weston assessed performance by measuring speed and accuracy in marking certain rings (Sundstrom, 89).

By this approach Weston presented "visibility". Blackwell made several researches in 1959 and 1970 which present the same relationship between lighting and performance. The idea is more and more light was required to sustain a constant level of performance in terms of visual difficulty such as smaller details and lower contrasts. The researches of Blackwell is important because it formed the basis for the U.S. Illuminating Engineering Society Standards of lighting in the work place (Sundstrom, 90).

The later researches were conducted in real offices with the participants. Sundstrom (90) points out that, those studies were begun after 1975 by Henderson, McNellis, Williams, Hughes, Smith and were expected to perform actual office tasks under varying levels of illumination. The tasks were check-reading, reading and typing, standard reading test, proofreading and number verification. With these studies researchers found out the effects of difficulty levels of task and the effects of lighting depend on the age of the worker (Sundstrom, 90-91).

As a summary, researches on intensity of lighting show that the visibility of details is declined by decreasing contrast and size of details. The contribution of lighting to performance is less than visibility. Performance increases with added light with following principle of diminishing returns.

2.3.1.2. Quality and Distribution of light

The research about the quality and distribution of light brings out a word called "phototropism" which means attraction of looking steadily or fixed to bright sources of light. This was conducted by Hopkinson and Longmore In 1959. One idea behind phototropism was the bright sources of light can cause distractions and for some tasks include impaired performance.

Second idea about the beneficial implications for performance, is to take the workers attention or gaze in the work but it is acceptable for some workers.

But phototropism arouse the problem of direct and reflected, discomfort and disability glare by McCormic in 1976. This is the most important study in the name of quality and distribution of light (Sundstrom, 93).

2.3.1.3. Lighting and Satisfaction

Most of the people in offices ignore the importance of lighting, unless they have a reason to notice it. When it is asked to people about their lighting, mostly the answer is that - more light is better, but excessive light can create glare and dissatisfaction. Satisfaction is dependent on law of diminishing returns (Sunstrom, 94).

In the field studies for satisfaction, researchers deal with a reasonable level of satisfaction with lighting. It came out by a project in 1981. This is the connection between the intensity of lighting and satisfaction with the physical environment. At the end of the studies it was found out that the higher levels of satisfaction were held with brighter light but some eye problems reported

in some studies. In laboratory experiments it is suggested that people were satisfied with modest lighting intensity. More light can increase satisfaction but brings problem of glare. The last finding is the quality of lighting is important for satisfaction (Sundstrom, 95).

2.3.2. Psychological Effects on Human Performance

Psychologists have developed theories for short-term influences of the work place on the performance of office workers. The theories about the physical environment are psychological arousal, stress, distraction, overload, concept of fatigue as pointed out by Sundstrom (65). Also Crouch and Nimran (209) state this point as relevant literature and suggest that the physical environment might affect performance through various psychological processes such as arousal, stress, distraction and fatigue.

Cohen (25) stressed the eye fatigue problem when improper lighting placing relation with performance. The impact of the physical environment on performance depends upon the demands of the task. If the work place adds to a worker's level of arousal and performance, it should be improved if the added stimulation brings the worker's arousal into the optimal range. On the other hand, performance should decline if the extra arousal takes the worker's arousal beyond what is optimal. For relatively undemanding tasks, added arousal is more likely to help than hurt performance, as such tasks have a relatively high optimal level of arousal (Sundstrom, 65).

Environmental stress is defined by Sundstrom (68) as, "a form of psychological and physiological mobilization in response to perceived adversity , demand , challenge or threat". Sundstrom (68) continues his opinions about this subject as, the environment can act as a source of distraction and can be defined as a diversion attention from the task and as an impediment to the performance. Sensory overload, refers to excessive stimulation that contains no specific meaning for the individual. Information overload refers to sources of stimulation that carry meaning and call for a response, overload occurs when information comes faster than it can be assimilated and dealt with. Fatigue may occur in work environments that necessitate uncomfortable postures, strenuous movements or awkward procedures. These conditions resulting in either better or poorer performance.

Another approach to the subject is from Mahnke and Mahnke (32), the biological effects that do not known and concerned. The light radiation has effects like activation of pineal organ, endocrine and autonomic effects, effects on performance and fatigue, cognitive, behavioral, and emotional correlates.

Also another work done by Igor Knez (41-50) about the indirect effects of lighting on human. In his work he did two experiments that has a general aim to examine affect of luminous environment on cognitive performance via

mood. He used warm and cool light sources and different levels of illumination. In the results of these experiments he got, positive mood was best preserved in the 'warm' light source at dim 300 lux and in the 'cool' white light source at bright 1500 lux. Also an interaction between color temperature illuminance showed that the problem solving performance was enhanced in the room light condition that accounted for the best preservation of the positive mood. Also another result about the work was that subjects' prefer 'warm' and dim versus 'cool' and bright light (Knez, 41-50).

A research Veitch and Gifford (454-455) worked with Lighting Beliefs Questionnaire (LBQ) that is a questionnaire containing 32 questions, asking for the beliefs of people about psychological and physiological effects of lighting. The results they have got, was very encouraging; 65% of the respondents reported that the quality of light is important. A large majority of respondents, as a percentage of 80.5, strongly agreed the natural daylighted indoors improve their mood but at the same time 70% type of lighting is also very important for their mood. Another interesting results were, an important number of respondents reported that bright lights stimulating and give feeling of energy inside. 14.8% people gave answers that they complete more work under bright light. But on the contrary forty percent of the respondents reported that bright light make them feel tense.

Lighting can play an important role on the reinforcing of spatial perception, activity, and mood setting. Mood is very dominant on human performance

and lighting create different types of mood on human like; somberness, playfulness, pleasantness, tension, etc.,. Also impressions of perceptual clarity, spaciousness, relaxation, privacy are another factors which are very effective on human performance (IES, 2-1,2-2).

2.3.3. Physiological Effects of Lighting on Human Performance

Human performance does not stay stable all day long and shows some differences. This situation is affected by some physiological situations, these are; loss of energy, changes in systems like respiration, circulation, nerve, muscle, etc., fatigue in nerve and muscular system and pressure on the sense organs (Estas, 420).

Knez (41-50) worked on mood and cognition in his experiments. But one part of these experiments was related with the effects of illuminance levels and color temperatures, combined with gender effect. In both experiments he used different lamps having different properties. In the first experiment he used Osram, 36W, L36/32, 3000K: 'warm' white vs. L36/22, 4000K: 'cool' white: CRI (Color Rendering Index)= 95 for both color temperatures. For the second experiment, he used General Electric, 36W, F36/29, 2950K, CRI= 51": 'warm vs. F36/33, 4200K, CRI= 58: 'cool' white light source. In both experiments illuminance levels were; dim 300 lux, bright 1500 lux and the gender were taken into consideration in the results. In the first experiment he obtained that different type of lamps change the mood of subjects. An

interaction between color temperature and gender showed that the 'cool' room light induced least negative mood in males, and that 'warm' room light for the same effect in females at high CRI at 95. However, in experiment two no gender effect was obtained, this means that the room light conditions at low CRI were not distinct enough to produce gender difference on room light evaluations (Knez, 41-50). In other words, the subjects' mood valences and their cognitive performance varied significantly with the genders' emotionally different reactions to the color temperature and combinations of color temperature and illuminance at different CRIs (Knez, 41-50).

In a research it was stated that, when the statement "Fluorescent lighting is bad for your health" was asked, it was observed that, nearly fifteen percent of people agreed with the statement. And nearly the twice of agreed people with the statement, strongly agreed that fluorescent lighting can give them headaches. Another result from research was an important range of respondents agreed that working under fluorescent lights can give them eye strain (Veitch & Gifford, 447).

2.4. Relationship Between Visual Performance, Human Performance and Lighting

People have many senses including vision. The eye converts light into a form that can be used by the brain. For human performance, vision may be the most important sense (Bailey, 54).

Visual performance is generally related with task, in combination of speed and accuracy, attributes that determine performance for clerical and industrial tasks (Ruck, 51). Erhard (22) gives the definition of visual performance from IES Lighting Handbook 1981 as "the quantitative assessment of the performance of a visual task, taking into consideration speed and accuracy". Contrast is the most important factor that effects the visual performance. Very small changes in contrast can make the difference between seeing and not seeing (Rea, 164).

Boer and Fischer (12) stated two approaches to get suitable lighting level for the performance of a given visual task. The first approach is to investigate the effects of lighting levels on visibility threshold (the degree of visibility) for artificial tasks under laboratory conditions. This offers an advantage of obtaining a sight into the limitations of the seeing process. Second approach is to investigate directly the effects of lighting levels on visual performance. Here the aim is to get conclusions concerning the effects of a particular lighting level in a particular situation.

As it was mentioned, in the previous sections, increased illuminance is an important factor on human performance. Human performance on the tasks follows the *law of diminishing returns* (Ruck, 51). This law is explained by Boyce (62) as, "equal step increases in illuminance lead to smaller and smaller changes in visual performance until saturation occurs". The illuminance at which performance saturates depends on the visual difficulty

of the task, which can be classified according to the size and contrast of the critical detail. Saturation occurs the smaller the size, the higher the illuminance and also at the opposite situations (Ruck, 52).

The Landolt Ring task is a standard visual performance test. Subjects identify the cardinal direction of a gap in a circular ring. The subjects perform the Landolt Ring task for various contrasts, luminance conditions, and viewing distances (Veitch and McColl, 57; Boyce, 63).

2.4.1. Visual Acuity

Visual acuity is the eye's ability to perceive small details (Bailey, 60).

Snellen makes another definition of visual acuity with 'Snellen Fraction':

$$\text{Visual Acuity} = \frac{\text{Viewing Distance (in meters)}}{\text{Letter Size (In M-units)}}$$

Distance as we know the measurement unit in meters but M-units is defined by Louise Sloan. 1 M-unit subtends 5' of arc at 1 meter. For example; 4M letter at 4 meters or 6M letter at 6 meters, all refers to standard acuity (Kyoto, 2).

Acuity measures the resolution capabilities of the visual system in terms of the smallest high-contrast detail to be perceived at a given distance.

Typically acuity is measured at both far 6 m. and near 0.4 m. viewing

distances (Olzak & Thomas, 7-45, 7-50). There are also factors affecting visual acuity which are: luminance level, spectral composition of illumination, pupil size, viewing distance, and age. Age is an important factor effect the visual acuity, visual performance and at least human performance. This is a very sensitive chain. In older observers the eye sensitivity is decreased as the effect of passing years. The amount of light transmitted is reduced by 2/3 in a 60 year old eye because of decreased pupil size and increased density of the lens (Olzak & Thomas, 7-45, 7-50).

As the density of lenses increases, eye fluids and cornea become denser and the ability to bring close objects into sharp focus is reduced. An increase in illumination can reduce the impacts of these age related changes in visual performance. But increased illuminance can cause glare and older persons are often more influenced than the younger persons. Too much light can be as undesirable as too little (Eastman Kodak Company, 226).

Boer and Fischer (8) give information on a work of Boyce which about effects of age on visual performance. Boyce found that most difficult task results are affected by both age and illuminance. But he found that the performance of visually easier, simulated tasks was not affected by a change in illuminance. In all cases, he noticed an age effect on visual performance.

2.4.2. Visibility Approach

The visual difficulty of any task can be separated into individual elements called contrast, size, etc. The effects of different lighting conditions on each of these elements can be established separately and ultimately reassembled to predict the visual performance of any task (Boyce, 68). Boyce (68) defines visibility approach as “ the visual difficulty of any task is best measured by a single quantity which will reflect the integration of all the elements in the stimulus by a human observer”.

According to Munson (108) visibility is “the ease of performing a visual task and is generally dependent upon contrast and background luminance”. This can be calculated or measured by a technique or method referred to as equivalent sphere illumination, or ESI. Equivalent sphere illumination is a method for evaluating the visibility of a task as it is measured. This is like to compare the two task locations by adjusting the light level on task in a sphere. One task is on outside and the other one is in the sphere. This measurement is for proper visibility to obtain in working environments (Munson, 109). Each task was to be compared to a reference task to determine its visibility in terms of revealed contrast. For the relationship between ESI and visibility level relationship, Veitch and Newsham’s (2) work about determinants of lighting quality can be checked.

3. MEASURING HUMAN PERFORMANCE

Peter Ellis (227) explains man-environment relation and how it became clear in last years with these words:

The theoretical assumption that often underlies simulation studies is that the organizational context and the design management process are not relevant to the measurement of user responses. This implies a particular theoretical model for man-environment relations, one that assumes human reactions to environments are fixed and unchanging. It is a mechanistic model and takes for granted the idea that the "performance" of human beings can be measured and generalized in the same way that the performance of physical components of the environment can.

Here we see that Ellis takes human performance measurement as a model for man-environment relationship and another approach of him is to generalize them for daily life. According to Bailey (10) any performance standard must met according to some standard. Without a standard, performance cannot be made, at least at a level where suggestions for improvement can be made. The standards must be known to the user, and be meaningful and measurable. The standards are, roughly, the measuring types.

Human performance should be measured using a clear and compatible set of performance measures. The focus of measurements should be on a particular group of people performing the same activity in a similar context. The data must be collected over a period of time then can be compared with a standard (Bailey, 13).

According to Bailey (10) adequate human performance can be measured using accuracy, speed of performance, training time, and user satisfaction. Measurement can be made with using one or all of these performance measures. But while measuring human performance; human characteristics, the activity being performed, and the context in which the activity is performed must taken into account.

3.1. General Measuring Types

To measure the height of a wall, we might refer to the number of meters on a tape measure and to measure the weight of oranges in a basket, we use kilos recorded on scales. These are all dependent on standards (Bailey, 13).

3.1.1. Measuring Accuracy

Measuring accuracy depends on performing an action with the fewest errors. Measuring the relative proportion of errors made in a given time gives an indication of how closely a user meets the standard set for that work. Also inspecting the errors may help explain why a person may not be achieving the required level of performance (Bailey, 5). In addition Bailey (11) states

that one of the main goals of any system is fewer errors in other words, acceptable human performance is to have activities performed in a reasonable time with few or no errors. When measuring accuracy, the data should be collected over a period time long enough to get reasonably reliable results.

3.1.2. Measuring Speed of Performance

If efficiency in a system improved, then it means the speed of human performance reduced to a minimum. The prediction of efficiency is based on the study of variables affecting the speed of performance in many different activities. The aim of designer is to have activities performed in the shortest possible time. This results are mostly for, most work being performed per person in a given time, and a need for the fewest people (Bailey, 11).

3.1.3. Measuring User Satisfaction

This is an another standard that may turn out to be the most critical one. It concerns whether or not the human performing an activity in a particular context receives satisfaction. A system should be build that will allow work to be done in the shortest time, with few errors, and at the same time satisfy the worker. We have to think that people are willing to spend many hours in these spaces. Satisfaction is usually measured indirectly using interviews or questioners (Bailey, 12).

3.1.4. Measuring Training Time

The final important performance measure is the total training time required to bring human to a desired level of performance. Less time to train people, the lower cost of operating system. Fewer errors require fewer corrections.

Shorter processing times require fewer people. Bailey stated that "Reducing errors, processing time, and training time all contribute to a system that costs less to operate" (Bailey, 12).

These four standards according to Bailey (13) are important for human performance. These standards are for to do the work with greatest possible accuracy within the shortest time. In addition to these, the performance itself should be satisfying, necessary and unique skills should be developed in shorter times. These four standards should be designed for achieving an acceptable level of human performance.

3.2. Methods of Measuring Performance Under Lighting Conditions

Hughes and McNelis (32-38) in their work, use visual search as first task.

The process is to search for the numbers which was written on a paper in mixed form. The process was repeated under three different lighting levels.

The occupants asked to make a visual search and find out the required number under different lighting levels. In the second part of the study the occupants asked to do visual paired comparisons task. The process is to match the two columns of number and letter combinations on a paper, again

under three different lighting levels. In this thesis, the case study on the effects of different types of lighting on human performance was inspired from the second part of this study.

Rea (1964) made studies about contrast effects on visual performance.

Contrast because it is such an important factor determining subjects' behavior at a task. Changing contrast have very large effect on human performance.

In previous studies different measuring types were used. Katzev (1975-1978) used typing test printed on both glossy and plain paper, entering data on a standard spreadsheet, detecting errors in written material, comprehension in reading matter, and self reports of temporary moods as anxiety, arousal, and fatigue.

Smith and Rea (1979-1983) used reading test in their study. In this study the level of comprehension (depth of understanding) and the speed of comprehension (time and accuracy) were searched in the terms of good and poor quality copy texts. According to the results there was a small but highly significant decrement in reading performance for the poor copy condition but no consistent statistically significant differences for light level or age. On another work by Smith and Rea (1987-1992), they studied proofreading test under different levels of illumination. As a result, task performance was improved as illumination was increased to the highest level which was used

in the study. Also Rea (41-57; 128-142) made studies on visual performance similar with the previous examples. Smith and Rea (47-52) made another study on the visibility of bank cheques. They compared handwritten four digit numbers on personal cheques with the typed numbers on sheet paper.

Barnaby (20-28) made another experiment on the relationship of illumination and performance. He used speed and accuracy for cross checking test under different lighting levels. This study was similar to the other studies on the subject. But the only difference was that Barnaby realized this study considering cost and saving relationship in his company.

For measuring visual performance Rea et al (1-3) used some tasks like numerical verification task, readability rating and pupil size. Numerical verification task was like matching test. Here the occupant expected to compare two lists as quickly and as accurately as possible. In readability test, after completing each trial occupants expected to write a number from 0 to 10 as their readability of the reference sheet presented during trial. In pupil size task, the effects of changes in brightness on pupil size were measured by special equipments.

A work done by Veitch and Newsham (3-13) about quality of lighting and its effects on task performance, mood, health, satisfaction and comfort. Veitch and Newsham have proposed a behaviorally based definition of lighting quality and quality exists when the luminous conditions are suitable for the

needs of people who will use the space. They grouped and worked with these six categories; 1)visual performance (measurement by VALID - Vision and Lighting Diagnostic Kit - The VALID kit consist of a standard task, which is viewed under uniform lighting provided by a hemispherical dome illuminated by incandescent lamps. Tiller and Phil, 1-2), 2)post-visual performance (e.g., reading, sewing, walking, etc.), 3)social interaction and communication, 4)mood state (happiness, alterness, satisfaction, preferences), 5)health and safety, 6)aesthetic judgments (assessments of the appearance of the space or the lighting). The study was one-day study and subjects worked under different lighting conditions in specially designed individual office units. In this program every hour was planned like standard office working day. The aim of this study was to point out the importance of lighting quality in working environments.

Some research studies for searching lighting systems and luminaries for improving the human performance in working environments have been also realized in the recent years. "Effects of lensed-indirect and parabolic lighting on the satisfaction, visual health and productivity of office workers" is the one of these kind of studies (Hedge, Sims and Becker, 260).

4. LIGHTING CONDITIONS AND PROCEDURES FOR IMPROVING PERFORMANCE

Designing lighting for working environments contains more than calculation and luminaire selection. A designer must have an understanding of human visual system and visual performance. All office work type jobs are related with visual works. In this chapter, lighting conditions which are affecting the human performance, conditions and procedures for improving performance and creating pleasing working environments were discussed.

Before going into the lighting conditions, we have to evaluate the effects of lamp types on human performance. Fluorescent lighting that has similar color rendering as natural daylight is superior to other types of fluorescent lighting in terms of health and productivity effects (Veitch, 254). Karpen (6) defines fluorescent lighting that is similar to natural daylight "It is commonly called full-spectrum lighting. This is a lamp having a color rendering index of 90 or above and a correlated color temperature of 5000 Kelvin or above. These lamps closely match the spectral energy distribution of the overhead sun and sky." According to Veitch (254), in her work with Gifford and Hine, demand characteristics and full-spectrum lighting have effects on performance and improvements on reading performance even both favorable and unfavorable information about full-spectrum lighting were given to the occupants. In addition to these, further information about effects of full-

spectrum lighting on people can be obtained from the study of Jennifer A. Veitch and Shelley L. McColl (53).

4.1. Luminous Environment Considerations

In this part , we will try to examine some general luminous conditions and their successful implementations for providing optimum performance or improving the performance of the workers in daily working environments.

The visual impact of a working space depends on variations in perceived illuminance and color. These can be achieved by surface reflectance variations, color variations or by illuminance variations (ANSI/IESNA, 1).

The color, both surface color and light source color, play an important role in working space lighting environment. Color adds some psychological meaning into the spaces like; interesting, inviting, pleasant, cool, etc. Light source color determines the general overall appearance of people, furnishings, and room surfaces, in another words light source color indicates the general atmosphere of the working environment. This depends on two considerations about the light source color: chromacity and color rendering provided by the light source. Chromacity refers to the color appearance of the light source and it is designated by its color temperature in Kelvin. Color rendering refers “the appearance of colored objects when illuminated by a particular light source as compared to their appearance on a reference source” (ANSI/IESNA, 1-2).

Another important point in the luminous environment that we have to consider is the luminance differences which is very necessary for vision. An interior space is seen and interpreted easily because of the luminance differences of the surfaces. The result is the same for a paper task due to the difference between background and detail. Perfect uniform illuminance on all surfaces and no variation in their reflectance cause a complete disorientation. On the contrary a large difference in the luminance within the field of view is distracting and can cause glare. The balance between total luminance and distracting extremes of luminances have to be taken into consideration. It is important to provide proper visibility to the worker, to get optimum performance (ANSI/IESNA, 2-3).

For a working environment, luminance near each task and in other parts of the interior within the field of view should be balanced against the task illuminance. The luminance ratio between the different tasks and areas effect the transient adaptation. The eyes adapt themselves for optimum vision when moving from one luminance level to another. If there is luminance difference between two areas or two tasks, the visual assimilation may be slower as the eye move from one luminance level to the other. Improper luminance level differences cause another unwanted effect which is disability glare. Glare sources in the field of view, alters the luminance of the image and its background and reduces the contrast so that visibility may be reduced, as the performance at the same time (ANSI/IESNA, 3). Flynn

(38) states that visual comfort probability (VCP), having the minimum shielding angle which equals to 70 and 45 degrees is enough to minimize user glare problems.

The luminance ratio between the task and more darker surfaces is also related with reflectance of the surfaces as well as the luminance falling on each. The degree of specularity (gloss or shine) on working surfaces should be considered. They will reflect the light like a mirror image in the downward light distribution of direct luminaries (ANSI/IESNA, 3).

While working on a task, these luminous environment considerations are important. Because the visual comfort which is provided from the luminous environment may cause annoyance, discomfort, or loss of visual performance and visibility, and in total the loss of human performance in the working environments (ANSI/IESNA, 4).

4.2. Visual Task Considerations

Working environments include a variety of difficult visual tasks. Lighting for these environments should provide optimum conditions for the various visual tasks performed. Contrast with the background, size, task luminance, and the time duration for viewing determines the visibility of the details of a task. Another factor that effects the visibility is age, which is a physical factor of human. The main topics about visual task considerations are quality of

lighting, quantity of illuminance and illuminance selection procedure (ANSI/IESNA, 5).

Munson (100) pointed out that before designing for lighting, the task must be defined. If it can be defined, designer can find a proper solution to lighting problem. In this century, occupants are exposed to a great variety of visual tasks having different varieties of visibility from excellent to very poor. Improving the quality of the task can be achieved by improving the lighting system to adapt the human eye to the various tasks.

In case of increasing performance, Vischer (195-202) makes a different suggestion. Like Munson, she is pointing out the importance of analyzing the visual demands of workers' tasks before designing the lighting of their work spaces. People's lighting requirements may change as their tasks change during the day or over several weeks. Then the people's lighting requirements can be individualized. This means that designing a lighting system give chance to occupants to adjust many aspects of their lighting conditions as possible as without having a negative impact on the other workers in the space. Kleeman et al (211) makes the same suggestion as more individual control on lighting for improving the performance.

As already known the task needs some luminance for becoming visible. The eyes sensitivity to contrast increases while the luminance increases. In the light of this explanation, we can say that the better contrast, the better

visibility. For any visual task of paper work, the sizes of type have to be considered. Too small or too large in size, effect the visual performance (ANSI/IESNA, 5).

In this modern life-style context “the time” has great importance for almost every job and occupation. Accuration and speed in the work are both valid concepts for today’s modern office-life. ANSI/ Standard Practice Subcommittee of the Office Lighting Committee of the IESNA (6) gives a brief information about the importance of time in terms of lighting and its components:

The rate at which the visual system can acquire information is related to the visibility of the task. If visibility is poor, due to small size, low contrast, or low luminance, the rate of assimilation decreases and the work takes longer. If the rate of assimilation is to be maintained under conditions of poor visibility, accuracy of assimilation will suffer. Accuracy, however, is more important for some tasks than for others.

Munson (100) supported the opinion of ANSI/IESNA and added as “when accuracy is important, all factors must be optimized to assure accuracy and speed of work.” To this point we tried to examine the general requirements of any kind of visual tasks. Quality of lighting, quantity of illumination and illuminance selection procedures are other conditions and must be taken into consideration for improving human performance in working environments.

4.2.1. Quality of Lighting

Quantity of illumination is not the only condition that effects the human performance. Other than the quantity of illuminance of the task, the visibility of task will be effected by the location of the luminaries relative to the task. The distribution of the luminaries, the task itself and the work surface, also have important roles. These factors can cause veiling reflections, reflected glare, and cause shadows which can result in reduced contrast and visibility (ANSI/IESNA, 6).

Contrast is very important for visibility as discussed earlier. The degree of contrast for white paper tasks depends in part upon the glossiness of the dark task details and upon the relative locations of the light sources, the task and the eyes. While performing a task, an image of a luminaries or bright ceiling happens to be reflected in the details of the task. Because of this, contrast will be reduced and visibility will be impaired. This effect is called “veiling reflections” (ANSI/IESNA, 6). The three points should be considered while studying veiling reflections is; the visual task, the workers’ orientation and viewing angle, and the lighting system (IES, 2-25).

ANSI/IESNA (6) defines the ‘offending zone’ as “the area of the ceiling where a luminaries would cause most of the veiling reflections”. Most of these reflections happens on specular or shiny materials. Flynn, et al. (46) states that veiling reflections follow the principle of ‘angle of reflectance

equals angle of incidence' and this ends up with decreased visibility. While studying the location of the luminaries they should be kept out of the offending zone in the frame of the three points consideration. We can provide one worker's placement as it is stated above. But, in a crowded working environment the realization of this placement is rather difficult in the context of providing working sites for all workers out of the offending zone. (ANSI/IESNA, 7). See Figure 4.1.

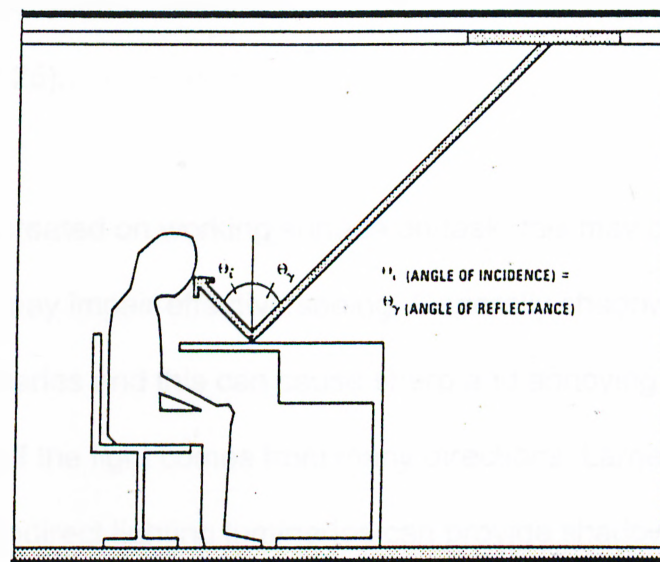


Fig. 4.1. Veiling reflections.

Flynn et al. 1992. *Architectural Interior Systems*. New York: Van Nostrand Reinhold. 49.

Glare is defined by the IES (3-12) "the sensations produced by illuminance within the visual field that are significantly greater than the illuminance to which the eye is adapted, and which causes annoyance, discomfort, or loss in visual performance and visibility". On working surfaces, we meet with reflected glare which is almost as annoying as direct glare. It is caused by mostly specular or shiny surfaces like highly polished or glass surfaces. It

can be reduced by the use of matte surfaces and by carrying out the procedures for reducing veiling reflections on the task. Another solution may be large area low-luminance luminaries or indirect luminaries (ANSI/IESNA, 7). According to Soewarno (326), providing a good level of general illumination which can be done by numerous small light sources to reduce reflected glare, will reduce the brightness ratio between the work area and its surrounding area. If the reflections are of high luminance, they also may produce disability glare if near the line of sight and may prove distracting to workers (IES, 2-25).

If shadows are created on working surface on task, this may cause reduction of the task and may impair effective seeing. Generally shadow caused by location of luminaries and this can cause sharp and annoying effects. This will be softened if the light comes from many directions. Large area luminaries and indirect lighting luminaries can provide shadowless working environments (ANSI/IESNA, 8).

Quality of lighting is not directly measurable, but is an emergent state created by the interplay of the lit environment and the person in that environment. According to Veitch and Newsham (120) good lighting quality exists when a lighting system creates good conditions for seeing, supports task performance or setting appropriate behaviors, fosters desirable interaction and communication, contributes to situationally appropriate

mood, provides good conditions for health and avoids ill-effects, and contributes to the aesthetic appreciation of the space.

Quality of lighting may be improved by balancing the quantity of directional light with the diffused light in locations where people spend most of their time. Fletcher (122) studied the best balance between the directional beam and the diffuse light in the office. The best angle of incidence for the direct light also be determined such that no disability or discomfort glare was experienced by the office worker.

4.2.2. Quantity of Illumination

An adequate level of illumination makes seeing easier, prevents needless waste of mental effort, increases performance, reduces errors and accidents, decreases fatigue, improves morale, promotes hygiene, brightens rooms and causes them look more attractive and keeps the workers happier in their work (Soewarno, 325).

Illumination levels preferred may be several times higher than those actually needed for good visual and task performance. As illumination increases, visual acuity increases. This increase causes higher levels of lighting and this allows for greater accuracy and for speedier performance of visual tasks, but that very high levels of illumination can inhibit performance (Lee, 30).

While designing lighting for working environments or buildings, the designer makes some assumptions due to unknown situation of the visual tasks and occupants, in detail. Designing modern electronic working environment, including the combination of paper and VDT (Visual Display Terminals) tasks which are going to be performed can be the main starting point (ANSI/IESNA, 34). ANSI/IESNA (9-10), IES Lighting Handbook Application Volume (2-5 - 2-20) gives recommended illuminance levels that can be achieved in buildings for the related tasks.

Another points related with the quantity of illumination and human performance are economics and energy considerations. If designer ignores the importance of energy economics it causes wasteful lighting system and pay for energy losses. A light is energized when not needed (poor lighting conditions), the lighting system is inefficient or of poor quality, the amount of lighting exceeds the needed and the amount of lighting is inadequate for proper task performance type conditions will cause energy waste when any of these conditions exists. When inadequate lighting is installed, productivity and human performance may be lost. Here important thing is the design could be tailored to the most severe visual needs that might be encountered. Also at the planning stage, task locations should be planned as related to the most efficient lighting layout (ANSI/IESNA, 8).

Human Factors Section, Health Safety and Human Factors Laboratory of Eastman Kodak Company(226) states that increases in illumination means

direct increase in cost. Energy conservation needs suggest the reduction of lighting levels wherever possible but the question is to find out that how to increase human performance while decreasing or not increasing the amount of energy used for lighting.

4.2.3. Illuminance Selection Procedure

Usually the required lighting levels depend on the difficulty of the task and the level of performance desired. Another point to consider is worker's satisfaction with their visual environment (Boer & Fischer, 12).

Illuminance selection procedure should be based on visual performance and task specific. Knowledge about the task is very important for designer.

Occupants and activities in the spaces are also other clues for the lighting designer. ANSI/IESNA (8) rises some questions that may help in illuminance selection:

- What are the tasks?
- How much time is spent on each task?
- What percentage of time is spent on each task?
- How important is accuracy for visual performance?
- How important is speed for visual performance?
- Which tasks are more visually difficult?
- What are the occupants' age?

These questions help to achieve proper lighting for visual performance and also for general human performance. IES Application Volume (2-3) agrees with this questions and adds a question about the reflectance of the task which will determine the adaptation luminance produced by the illuminance. The answers to these questions will determine the appropriate amount of light for the lighting task. Also IES established a procedure for selecting illuminance values in 1979 (Flynn, 74). IES Application Volume (2-4) explains the aim of this procedure as “the procedure provides a method for determining a target maintained illuminance value for a single task, and as such will not assure an adequate illuminance level for a given space”.

4.3. General Lighting Types in Spaces

Generally two methods of lighting tasks are used in spaces; general lighting and localized lighting. Designing general lighting helps to provide required illuminances at the various tasks. Localized lighting is designed to provide task illuminance with task lighting luminaries. When the general illumination cannot provide the required illumination for the task, localized lighting is used. (ANSI/IESNA, 34).

In the IES Lighting Handbook (2-31, 2-32), two types of classification are given. First classification is general lighting, localized general lighting, local lighting and task-ambient lighting. Second classification is according to CIE Luminaries type. These are direct lighting, semi-direct lighting, general diffuse lighting, semi-indirect lighting and indirect lighting.

Here, two types of general lighting was discussed, these are direct lighting and indirect lighting. Only, cove lighting, wall washing and uplighting systems of indirect lighting were discussed for the reason of which they were used in the experimental study.

4.3.1. Direct Lighting

Direct (downward) lighting provides equal levels of illumination across large spaces, which is necessary when activity or task location within space is unknown (Munson, 125). IES Lighting Handbook Application Volume (2-32) classifies or defines direct lighting "when luminaries direct 90 to 100 percent of their output downward, they are from a direct lighting system".

Direct lighting units can bring some problems to the working environments in terms of hindering performance. Some problems are reflected glare, high reflectance room surfaces, and veiling reflections (IES Application Volume, 2-33). To prevent this problematic conditions in direct lighting diffusers, lenses, polarized panels and parabolic louvers can be used (ANSI/IESNA, 39). Also another problem is the direct glare, and brightness control media is required for reducing this effect (IES, 2-33).

Task lighting is another type of direct lighting. Task lighting can provide illumination where it is more needed, on work surface, more economically than the most energy-efficient ceiling luminarie, because task lighting is

located closer to the work surface. The result can be significant energy savings and improved visibility for workers (Wolsey and Miller, 1).

4.3.2. Indirect Lighting

Indirect lighting is reflected from a secondary surface, such as ceiling or the walls or a combination of both. The use of indirect lighting in working environments provides a near shadow-free environment similar to the conditions under an overcast sky. In providing this near shadow-free environment, objects such as partitions and desks tend to lose definition due to a lack of contrast. Task brightness will appear dark in comparison to the ceiling brightness. The eye adapts to the brightest object in the visual field, In this case the ceiling. It will take longer to adapt the task brightness, since its illuminance value is less (Munson, 127).

According to ANSI/IESNA (40), indirect lighting can provide a calm, diffuse light besides highlights and shadows. This absence of highlights and shadow can provide good visual task illumination. It may reduce a sense of visual clarity, depth perception, visual cues or a sense of orientation. The main problem can be addressed by the addition of accent lighting or wall washing, which will establish visual cues, make it easier to interpret the visual environment, and add to the pleasantness of the space.

The ceiling and the high parts of the walls must reflect light to the work plane and these surfaces should have high reflectances (IES Application Volume, 2-34). Indirect lighting has kinds of lighting systems. Three of them are, cove lighting, wall washing, and up lighting. We will discuss these kind of lighting systems. According to Lechner (300), these lighting systems known as architectural lighting.

4.3.2.1. Cove Lighting

It is a system that we obtain indirect light from continuous wall-mounted fixtures and it directs all light through the ceiling (Lechner, 300). Cove lighting is soft, uniform and create a feeling of spaciousness. The cove must be designed that have properties like no direct view of light source, far enough from the ceiling to prevent excessive brightness right above the lamps, and the inside of the cove, the upper walls and the ceiling must all be covered with a high reflectance of white or near white paint (IES 5-23; Lechner, 300). In cove fluorescent, linear incandescent, cold cathode, large fiber optics, or prismatic tubes can be used as light source (Grosslight, 163).

The cove should be installed at least 25.5 cm down from the ceiling (Grosslight, 163). If the cove mounted is 30 cm below from the ceiling, the lamp center from the wall should be 6 cm or more from wall. If cove is 38-50 cm down from the ceiling, the lamp center should be 9 cm or more. When opening between ceiling and cove is between 53-76 cm, then lamp center

from wall should be 11 cm or more (IES Lighting Handbook, 6-25; Grosslight, 40-44).

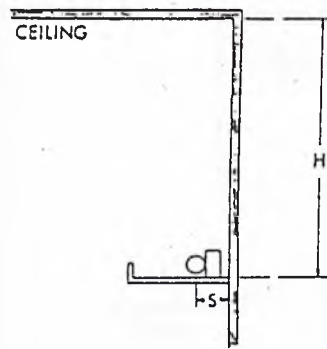


Fig. 4.2. Cove Lighting with fluorescent bulb.

IES Lighting Handbook: Application Volume. 1984. New York: Illuminating Engineering Society of North America, p. 6-25.

4.3.2.2. Wall Washing

Wall washing consist of mounting fixtures on or near walls, and directing light downward to more or less graze the walls. The closer the fixtures are to the walls, the more pronounced the grazing effect will be, and the greater the shadowing on uneven surfaces (Lindsey, 343). If we position the fixtures away from the wall so that the wall will be evenly illuminated. According to Lechner (301) wall washing type lighting fixtures increase the brightness of the walls, emphasize the texture or certain features on the walls. See Figure 4.3.

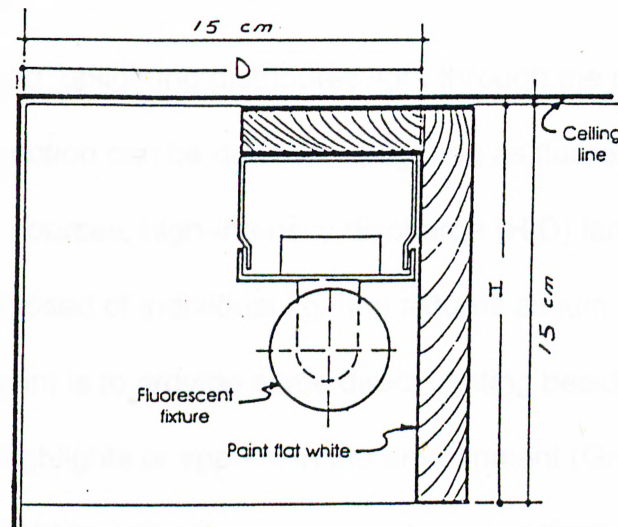


Fig. 4.3. Dimensions for wall washing with fluorescent bulb.

Grosslight, Jane.1990. *Light, Light, Light*. 2nd ed. Tallahassee: Durwood Publishers, 43.

Lamp selection is important for wall washing. It is mostly selected as incandescent or fluorescent lamps. There is an important point about fluorescent lamp installation. During the installation, their standard lamp length must be taken into consideration in order not to leave unlighted parts. (Grosslight, 43). Lechner (301) pointed out the minimum dimension for distance between wall and the piece to cut the direct glare in front, as approximately 20 x 20 cm. He also adds, viewing angle of the user ought to

be considered since it may cause direct glare. The wall and inside of the washer should be white and matte finish.

4.3.2.3. Uplighting

As an indirect lighting, uplighting distributes light through the ceiling or to the corners. Source selection can be done for uplighting as fluorescent lamps, incandescent point sources, high-intensity discharge (HID) lamps. This system can be composed of individual lighting fixtures as luminaries or fixed systems. Another point is to provide some direct lighting besides indirect lighting to provide highlights or sparkle in the environment (Grosslight, 163-165). With indirect lighting, we can always meet most performance criteria for a glare-free environment (Salomon, 133).

5. AN EXPERIMENTAL STUDY ON THE EFFECTS OF DIFFERENT LIGHTING TYPES ON HUMAN PERFORMANCE

This study is related with the effects of lighting on human performance. The study mainly aimed to find out the effects of different lighting types with the same illuminance level, on human performance. In the study room, lighting installations, such as cove lighting, wall washing, uplighting, have been installed last year by Banu Yucetas for her study on “Effect of Different Lighting Arrangements on Space Perception”. In order to get the same level of illuminance on the work surface, some instruments and luminaries were added. Under these lighting systems, performance of participants were tested in terms of speed of performance and accuracy. As personal data, the age, sex and eye deficiency of participants were collected.

5.1. Experimental Set-up

The study was carried out in room FC - 112, Department of Interior Architecture and Environmental Design, at Bilkent University in Ankara, Turkey. There were no windows and heating units. The furnitures which were left from the previous study were two tables, two chairs, three stools, three file cabinets. The room measures were 4.10 x 4.18 m., that is 17.138 square meters; and ceiling height was 3.84 m. Floor was covered with 30 x 30 cm. terrazzo tiles; walls and ceiling were painted in matte white.

As mentioned above, the study room had four lighting types which were downlighting, cove lighting, wall washing and uplighting which remained from previous studies. The downlighting was supplied by two 40 W , Philips TL54 fluorescent lamps. They had no reflectors and were mounted on the ceiling. The placement of downlights are shown in Figure 5.1. Cove lighting and wall washing have been designed in one unit, the dimensions and arrangement of which are given in Figure 5.2. They have been installed on two walls facing each other that were 4.10 m. in length. For these lighting systems sixteen Philips TL54 fluorescent lamps have been used. While twelve of these lamps were 40W, the remaining four of them were 20W. The color temperature of these lamps was 6200 K and their CRI was 72 (Yucetas, 37). Figure 5.3 shows the arrangement of cove lighting and wall washing in the room. The uplighting in the room was provided by two torcheres with dimmers. In the torcheres, 300 W tungsten halogen lamps having a color temperature of 3000 K and an accepted CRI of 100 were used.

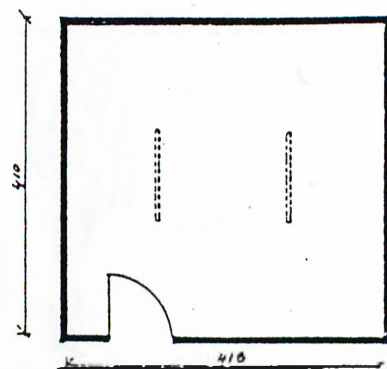


Fig. 5.1. The downlighting fluorescent lamp installations.

Yucetas, Banu 1997. *"The Effect of Different Lighting Arrangements on Space Perception."* Diss. Bilkent University. 35.

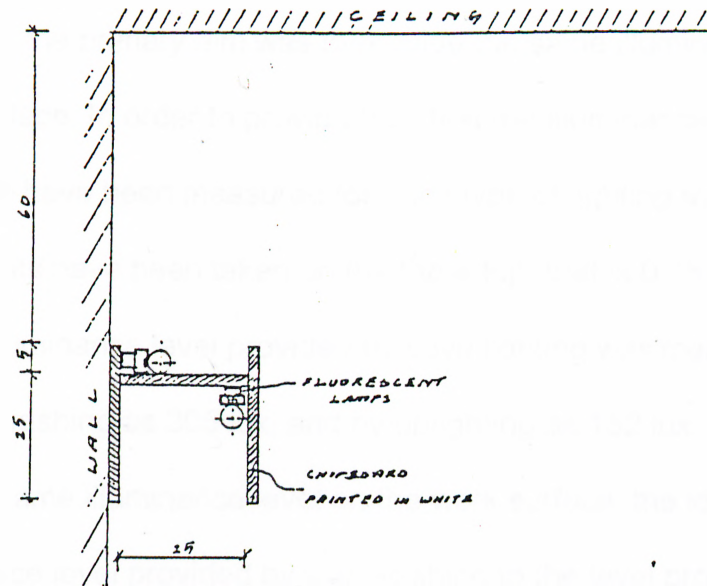


Fig. 5.2. Cove lighting and wall washing installation dimensions.

Yucetas, Banu 1997. *"The Effect of Different Lighting Arrangements on Space Perception."* Diss. Bilkent University. 37.

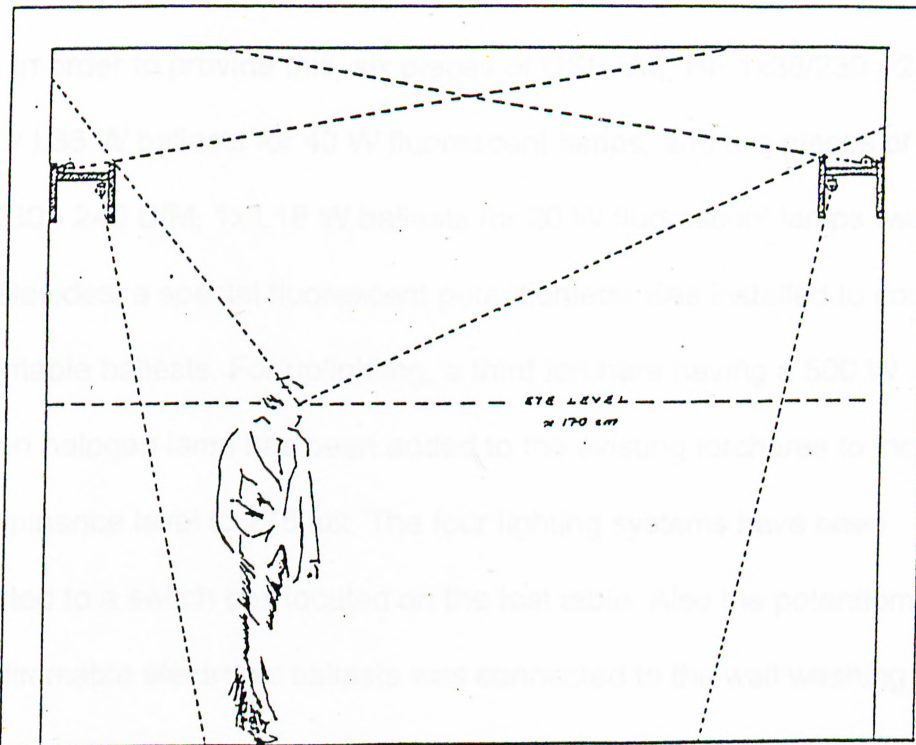


Fig. 5.3. Cove lighting and wall washing installations arrangement in room

Yucetas, Banu 1997. *"The Effect of Different Lighting Arrangements on Space Perception."* Diss. Bilkent University. 38.

In this study, the primary aim was to provide the same illuminance level on the work surface. In order to provide this, first the illuminance levels on the work surface have been measured for each type of lighting system.

Measurements have been taken on the table-top, that is 0.75 m above floor level. The illuminance level provided by cove lighting was measured as 275 lux, by wall washing as 305 lux, and by uplighting as 152 lux. In order to provide the same illuminance level on the work surface, the idea was to dim the illuminance level provided by wall washing to the level provided by cove lighting, which was 275 lux; and to increase the illuminance level provided by uplighting to 275 lux. For this purpose, dimmable electronic ballasts were installed for each lamp on the wall washing system to dim the fluorescent tubes. In order to provide this, six pieces of OSRAM, HF 1x36/230 - 240 DIM, 1x L36 W ballasts for 40 W fluorescent lamps, and two pieces of HF 1x18/230 - 240 DIM, 1x L18 W ballasts for 20 W fluorescent lamps were used. Besides, a special fluorescent potentiometer was installed to control all dimmable ballasts. For uplighting, a third torchere having a 500 W tungsten halogen lamp has been added to the existing torcheres to increase the illuminance level to 275 lux. The four lighting systems have been connected to a switch box located on the test table. Also the potentiometer of the dimmable electronic ballasts was connected to the wall washing switch.

The main reasons for choosing the room FC - 112 as the study room were that, the required lighting types have already been installed for the previous

study, and the room had no windows. Having no windows provided the elimination of the effects of daylight. The plan of the room is given in Figure 5.4. For the appearance of the room under four lighting systems, see Figures 5.5., 5.6., 5.7., 5.8.

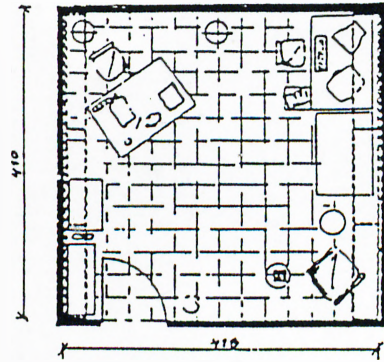


Fig. 5.4. Plan of the room FC - 112.

Yucetas, Banu 1997. "*The Effect of Different Lighting Arrangements on Space Perception.*" Diss. Bilkent University. 39.



Fig. 5.5. The appearance of the room FC - 112 under downlighting fluorescent bulbs.



Fig. 5.6. The appearance of room FC - 112 under cove lighting.



Fig. 5.7. The appearance of the room FC - 112 under wall washing.



Fig. 5.8. The appearance of room FC - 112 under uplighting.

5.2. Subjects

The participants of the study were the undergraduate students of Bilkent University, Department of Interior Architecture and Environmental Design. For this purpose, 90 students were randomly selected from all years of classes. Among these students, 52 were male, and 38 were female. As personal data, age, sex and correction in eye were collected. Each experimental session lasted for approximately 20 minutes.

5.3. The Procedure

The procedure consisted of the following steps:

- * When the students entered the room, the room was illuminated by standard downlighting fluorescent tubes which were not evaluated in the experiment.
- * Participants entered the room one by one and filled the three tests accordingly, on the test table.
- * During the experiments, while the subjects were filling the tests, only the coordinator of the experiments was allowed to control or change the lighting systems in each test.

The test was a matching test composed of two columns, each having 25 items. Each column consisted of the same items. The first column was the reference column and in the second column, which was the matching column, the items were mixed. Each item was composed of combinations of the letters 'B' and 'P' and numbers '5', '6', and '9'. The letters and numbers

were selected because of their circular and hook type characteristics and their similarity in appearance. But the combinations were selected randomly. A copy of one test page is given in Table 5.1. (For the test applied during the study, see pages at Appendix A).

During the experiments, three sequences in turning on the lighting systems have been determined. The sequence selection was made randomly but the main concern was to place each lighting arrangement in the first, the second and the third places once. The sequences were :

	<u>Position 1</u>	<u>Position 2</u>	<u>Position 3</u>
1st group →	uplighting	wall washing	cove lighting
2nd group →	wall washing	cove lighting	uplighting
3rd group →	cove lighting	uplighting	wall washing

Three groups consisting of different students were formed for the application of each sequence, in order to eliminate the effects of adaptation of the students to the test. Each group had 30 participants.

Collected data were analyzed by determining the time spent while filling the test, and the number of correct answers. As the next step, the maximum and minimum amount of time spent; the ratio between the number of correct answers and the time spent; and the percentage of the correct answers were computed. Also the relations between participants' age, gender, eye deficiencies and the lighting systems were investigated. In discussing the

results, the aim was to determine whether different lighting arrangements had effects on human performance or not.

Table 5.1. Example of the matching test.

<u>I</u>		<u>II</u>	
A.	PB596	<input type="checkbox"/>	PB699
B.	BP996	<input type="checkbox"/>	BP656
C.	PB956	<input type="checkbox"/>	PB556
D.	BP669	<input type="checkbox"/>	BP559
E.	PB566	<input type="checkbox"/>	PB966
F.	PB569	<input type="checkbox"/>	BP965
G.	PB966	<input type="checkbox"/>	BP596
H.	BP956	<input type="checkbox"/>	BP569
I.	PB659	<input type="checkbox"/>	BP566
J.	BP656	<input type="checkbox"/>	PB566
K.	BP695	<input type="checkbox"/>	PB659
L.	BP559	<input type="checkbox"/>	PB595
M.	PB695	<input type="checkbox"/>	BP996
N.	PB699	<input type="checkbox"/>	PB656
P.	BP596	<input type="checkbox"/>	BP659
Q.	PB556	<input type="checkbox"/>	PB596
R.	PB655	<input type="checkbox"/>	PB965
S.	BP965	<input type="checkbox"/>	BP655
T.	BP566	<input type="checkbox"/>	PB655
U.	PB656	<input type="checkbox"/>	PB569
V.	BP569	<input type="checkbox"/>	PB956
W.	BP659	<input type="checkbox"/>	BP695
X.	BP655	<input type="checkbox"/>	BP956
Y.	PB595	<input type="checkbox"/>	PB695
Z.	PB965	<input type="checkbox"/>	BP669

5.4. Data Analysis

The hypotheses of the study are as follows;

Hypothesis 1: Under different types of lighting, performance of the participants may change.

Hypothesis 2: Under different types of lighting, the gender of the participants may influence their performance.

Hypothesis 3: Under different types of lighting, the correction in eyes of participants may not influence their performance.

The first phase of data analysis involved the preparation of tables showing the results of the tests of each group. In evaluating these tables, average age of the participants, percentage of correction in eye, percentage of male and female participants, minimum completing time for test, maximum completing time for test, mean completing time for test, average of correct answers per minute ratio, mean of correct, wrong and empty answers for each test in three groups were computed. The statistical data of each test for each lighting arrangement and for three sequences are given in Tables 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 5.10.

The effects of gender and correction in the eye on human performance were evaluated at the end of the study, but the effects of age could not be evaluated since all the attended participants were in the age range of 18-28, that can be considered as 'young' persons.

Table 5.2

Statistical data of uplighting system in group 1, position 1 (See page 60).

GROUP 1
TEST 1
UP LIGHTING

PARTICIPANT	AGE	SEX	CORRECTION	TRUE	FALSE	EMPTY	TIME(MIN)	TRUE/MIN	RATIO	TRUE %
1	21	F	NO	19	3	3	7	3		76
2	26	M	NO	25	0	0	4	6		100
3	24	M	YES	25	0	0	6	4		100
4	21	F	NO	23	0	2	5	5		92
5	21	F	YES	21	2	2	6	4		84
6	18	F	NO	24	1	0	4	6		96
7	23	M	NO	23	2	0	8	3		92
8	19	F	YES	25	0	0	6	4		100
9	19	F	YES	25	0	0	4	6		100
10	27	M	NO	25	0	0	7	4		100
11	21	M	NO	23	2	0	6	4		92
12	21	F	YES	18	3	4	7	3		72
13	20	F	YES	24	1	0	9	3		96
14	21	M	NO	25	0	0	5	5		100
15	26	M	NO	25	0	0	5	5		100
16	23	M	YES	20	1	4	7	3		80
17	21	F	NO	25	0	0	7	4		100
18	22	M	NO	19	3	3	7	3		76
19	21	M	YES	25	0	0	5	5		100
20	19	F	NO	16	4	5	7	2		64
21	23	F	NO	25	0	0	5	5		100
22	26	M	NO	25	0	0	5	5		100
23	26	M	YES	14	11	0	6	2		56
24	22	M	NO	25	0	0	7	4		100
25	21	M	NO	24	0	1	6	4		96
26	22	M	NO	24	1	0	5	5		96
27	25	M	NO	25	0	0	6	4		100
28	28	M	NO	20	5	0	6	3		80
29	22	F	NO	25	0	0	6	4		100
30	24	M	NO	23	1	1	4	6		92

AVERAGE AGE	22
CORRECTION%	30
GENDER M %	60
GENDER F %	40

MIN. TIME	4
MAX. TIME	9
TIME MEAN	6
TRUE/MIN A	4

TRUE MEAN	23
FALSE MEAN	1
EMPTY MEAN	1

Table 5.3

Statistical data of uplighting system in group 3, position 2 (See page 60).

GROUP 3
TEST 2
UPLIGHTING

PARTICIPANT	AGE	SEX	CORRECTION	TRUE	FALSE	EMPTY	TIME(MIN)	TRUE/MIN RATIO	TRUE %
1	21	M	NO	25	0	0	4	6	100
2	22	M	NO	25	0	0	4	6	100
3	22	M	YES	25	0	0	3	8	100
4	22	F	YES	25	0	0	5	5	100
5	23	F	NO	25	0	0	4	6	100
6	22	M	NO	25	0	0	4	6	100
7	23	M	NO	25	0	0	5	5	100
8	22	F	NO	25	0	0	6	4	100
9	23	M	NO	23	2	0	5	5	92
10	25	F	YES	24	1	0	6	4	96
11	19	F	NO	25	0	0	4	6	100
12	22	M	YES	23	2	0	7	3	92
13	22	M	YES	25	0	0	5	5	100
14	26	M	YES	20	5	0	6	3	80
15	24	F	NO	25	0	0	4	6	100
16	20	M	YES	25	0	0	6	4	100
17	25	M	NO	25	0	0	4	6	100
18	25	F	YES	25	0	0	4	6	100
19	23	M	NO	24	1	0	5	5	96
20	20	F	YES	23	1	1	7	3	92
21	21	F	NO	18	4	3	7	3	72
22	22	M	NO	25	0	0	6	4	100
23	21	F	NO	25	0	0	6	4	100
24	22	M	YES	25	0	0	4	6	100
25	21	M	NO	25	0	0	3	8	100
26	20	F	YES	25	0	0	4	6	100
27	22	F	NO	23	2	0	4	6	92
28	21	M	YES	25	0	0	7	4	100
29	20	F	NO	24	0	1	4	6	96
30	22	M	YES	23	2	0	5	5	92

AVERAGE AGE	22
CORRECTION%	30
GENDER M %	57
GENDER F %	43

MIN. TIME	3
MAX. TIME	7
TIME MEAN	5
TIME/MINA	5

TRUE MEAN	24
FALSE MEAN	1
EMPTY MEAN	0

Table 5.4

Statistical data of uplighting system in group 2, position 3 (See page 60).

GROUP 2
TEST 3
UP LIGHTING

PARTICIPANT	AGE	SEX	CORRECTION	TRUE	FALSE	EMPTY	TIME(MIN)	TRUE/MIN RATIO	TRUE %
1	24	F	NO	25	0	0	4	6	100
2	24	M	NO	25	0	0	5	5	100
3	23	M	NO	25	0	0	4	6	100
4	21	M	YES	25	0	0	6	4	100
5	22	M	NO	25	0	0	7	4	100
6	24	M	YES	25	0	0	6	4	100
7	24	M	NO	23	2	0	6	4	92
8	23	M	NO	25	0	0	4	6	100
9	23	M	NO	24	0	1	5	5	96
10	20	F	NO	25	0	0	4	6	100
11	27	M	YES	25	0	0	5	5	100
12	23	F	YES	23	2	0	4	6	92
13	21	M	YES	22	2	1	6	4	88
14	25	F	YES	23	1	2	4	6	92
15	24	M	NO	25	0	0	3	8	100
16	26	M	NO	23	2	0	3	8	92
17	23	F	YES	25	0	0	7	4	100
18	23	M	NO	25	0	0	5	5	100
19	21	F	YES	25	0	0	4	6	100
20	21	F	YES	25	0	0	6	4	100
21	22	M	NO	25	0	0	6	4	100
22	25	F	NO	24	0	1	4	6	96
23	27	F	YES	25	0	0	4	6	100
24	24	F	NO	21	2	2	5	4	84
25	26	M	YES	21	4	0	7	3	84
26	25	M	NO	25	0	0	5	5	100
27	21	F	YES	25	0	0	5	5	100
28	21	F	NO	25	0	0	4	6	100
29	19	F	NO	25	0	0	4	6	100
30	21	M	NO	23	1	1	4	6	92

AVERAGE AGE	23
CORRECTION%	40
GENDER M %	57
GENDER F %	43

TRUE MEAN	24
FALSE MEAN	1
EMPTY MEAN	0

MIN. TIME	3
MAX. TIME	7
TIME MEAN	5
TIME/MINA	5

Table 5.5

Statistical data of wall washing system in group 2, position 1 (See page 60).

GROUP 2
TEST 1
WALL WASHING

PARTICIPANT	AGE	SEX	CORRECTION	TRUE	FALSE	EMPTY	TIME(MIN)	TRUE/MIN RATIO	TRUE %
1	24	F	NO	21	2	2	3	7	84
2	24	M	NO	25	0	0	7	4	100
3	23	M	NO	23	2	0	6	4	92
4	21	M	YES	25	0	0	8	3	100
5	22	M	NO	25	0	0	5	5	100
6	24	M	YES	23	1	1	6	4	92
7	24	M	NO	23	1	1	8	3	92
8	23	M	NO	25	0	0	5	5	100
9	23	M	NO	21	1	3	5	4	84
10	20	F	NO	25	0	0	5	5	100
11	27	M	YES	23	1	1	7	3	92
12	23	F	YES	23	2	0	7	3	92
13	21	M	YES	25	0	0	5	5	100
14	25	F	YES	19	2	4	5	4	76
15	24	M	NO	25	0	0	4	6	100
16	26	M	NO	22	3	0	4	6	88
17	23	F	YES	25	0	0	11	2	100
18	23	M	NO	25	0	0	6	4	100
19	21	F	YES	25	0	0	4	6	100
20	21	F	YES	25	0	0	6	4	100
21	22	M	NO	25	0	0	7	4	100
22	25	F	NO	21	4	0	4	5	84
23	27	F	YES	25	0	0	5	5	100
24	24	F	NO	20	3	2	4	5	80
25	26	M	YES	22	2	1	9	2	88
26	25	M	NO	24	1	0	6	4	96
27	21	F	YES	23	2	0	7	3	92
28	21	F	NO	25	0	0	5	5	100
29	19	F	NO	24	0	1	5	5	96
30	21	M	NO	23	1	1	6	4	92

TRUE MEAN	24
FALSE MEAN	1
EMPTY MEAN	1

MIN. TIME	3
MAX. TIME	11
TIME MEAN	6
TIME/MIN A	4

AVERAGE AGE	23
CORRECTION%	40
GENDER M %	57
GENDER F %	43

Table 5.6

Statistical data of wall washing system in group 1, position 2 (See page 60).

GROUP 1
TEST 2
WALL WASHING

PARTICIPANT	AGE	SEX	CORRECTION	TRUE	FALSE	EMPTY	TIME(MIN)	TRUE/MIN RATIO	TRUE %
1	21	F	NO	23	2	0	7	3	92
2	26	M	NO	25	0	0	5	5	100
3	24	M	YES	25	0	0	5	5	100
4	21	F	NO	24	0	1	5	5	96
5	21	F	YES	25	0	0	5	5	100
6	18	F	NO	23	2	0	5	5	92
7	23	M	NO	24	1	0	6	4	96
8	19	F	YES	25	0	0	5	5	100
9	19	F	YES	23	2	0	5	5	92
10	27	M	NO	25	0	0	6	4	100
11	21	M	NO	25	0	0	4	6	100
12	21	F	YES	25	0	0	7	4	100
13	20	F	YES	25	0	0	7	4	100
14	21	M	NO	25	0	0	5	5	100
15	26	M	NO	25	0	0	6	4	100
16	23	M	YES	23	1	1	9	3	92
17	21	F	NO	21	2	2	7	3	84
18	22	M	NO	25	0	0	7	4	100
19	21	M	YES	23	2	0	5	5	92
20	19	F	NO	23	2	0	7	3	92
21	23	F	NO	25	0	0	4	6	100
22	26	M	NO	25	0	0	4	6	100
23	26	M	YES	22	2	1	4	6	88
24	22	M	NO	24	0	1	7	3	96
25	21	M	NO	25	0	0	6	4	100
26	22	M	NO	25	0	0	4	6	100
27	25	M	NO	21	3	1	7	3	84
28	28	M	NO	25	0	0	4	6	100
29	22	F	NO	25	0	0	4	6	100
30	24	M	NO	25	0	0	5	5	100

TRUE MEAN	24
FALSE MEAN	1
EMPTY MEAN	0

MIN. TIME	4
MAX. TIME	9
TIME MEAN	6
TIME/MIN A	5

AVERAGE AGE	22
CORRECTION%	30
GENDER M %	60
GENDER F %	40

Table 5.7

Statistical data of wall washing system in group 3, position 3 (See page 60).

GROUP 3
TEST 3
WALL WASHING

PARTICIPANT	AGE	SEX	CORRECTION	TRUE	FALSE	EMPTY	TIME(MIN)	TRUE/MIN RATIO	TRUE %
1	21	M	NO	25	0	0	4	6	100
2	22	M	NO	25	0	0	4	6	100
3	22	M	YES	22	1	2	5	4	88
4	22	F	YES	25	0	0	6	4	100
5	23	F	NO	25	0	0	5	5	100
6	22	M	NO	25	0	0	4	6	100
7	23	M	NO	25	0	0	4	6	100
8	22	F	NO	23	1	1	6	4	92
9	23	M	NO	21	3	1	5	4	84
10	25	F	YES	23	1	1	6	4	92
11	19	F	NO	25	0	0	6	4	100
12	22	M	YES	23	2	0	4	6	92
13	22	M	YES	25	0	0	4	6	100
14	26	M	YES	23	2	0	5	5	92
15	24	F	NO	24	1	0	5	5	96
16	20	M	YES	24	1	0	6	4	96
17	25	M	NO	23	1	1	5	5	92
18	25	F	YES	23	2	0	5	5	92
19	23	M	NO	24	1	0	6	4	96
20	20	F	YES	25	0	0	6	4	100
21	21	F	NO	22	1	2	8	3	88
22	22	M	NO	23	1	1	8	3	92
23	21	F	NO	23	2	0	7	3	92
24	22	M	YES	25	0	0	4	6	100
25	21	M	NO	25	0	0	3	8	100
26	20	F	YES	25	0	0	4	6	100
27	22	F	NO	24	1	0	7	3	96
28	21	M	YES	22	1	2	5	4	88
29	20	F	NO	25	0	0	3	8	100
30	22	M	YES	23	1	1	4	6	92

AVERAGE AGE	22
CORRECTION%	30
GENDER M %	57
GENDER F %	43

MIN. TIME	3
MAX. TIME	8
TIME MEAN	5
TIME/MIN A	5

TRUE MEAN	24
FALSE MEAN	1
EMPTY MEAN	0

Table 5.8

Statistical data of cove lighting system in group 3, position 1 (See page 60).

GROUP 3
TEST 1
COVE LIGHTING

PARTICIPANT	AGE	SEX	CORRECTION	TRUE	FALSE	EMPTY	TIME(MIN)	TRUE/MIN RATIO	TRUE %
1	21	M	NO	24	1	0	6	4	96
2	22	M	NO	25	0	0	8	3	100
3	22	M	YES	25	0	0	4	6	100
4	22	F	YES	17	4	4	7	2	68
5	23	F	NO	22	3	0	4	6	88
6	22	M	NO	25	0	0	4	6	100
7	23	M	NO	21	2	2	7	3	84
8	22	F	NO	25	0	0	6	4	100
9	23	M	NO	25	0	0	5	5	100
10	25	F	YES	20	2	3	6	3	80
11	19	F	NO	25	0	0	7	4	100
12	22	M	YES	24	1	0	7	3	96
13	22	M	YES	25	0	0	6	4	100
14	26	M	YES	21	4	0	6	4	84
15	24	F	NO	25	0	0	4	6	100
16	20	M	YES	17	6	2	8	2	68
17	25	M	NO	23	1	1	4	6	92
18	25	F	YES	25	0	0	5	5	100
19	23	M	NO	25	0	0	5	5	100
20	20	F	YES	25	0	0	8	3	100
21	21	F	NO	19	2	4	8	2	76
22	22	M	NO	25	0	0	6	4	100
23	21	F	NO	17	8	0	8	2	68
24	22	M	YES	23	1	1	5	5	92
25	21	M	NO	25	0	0	4	6	100
26	20	F	YES	25	0	0	5	5	100
27	22	F	NO	22	1	2	5	4	88
28	21	M	YES	24	0	1	5	5	96
29	20	F	NO	23	1	1	6	4	92
30	22	M	YES	24	0	1	4	6	96

TRUE MEAN	23
FALSE MEAN	1
EMPTY MEAN	1

MIN. TIME	4
MAX. TIME	8
TIME MEAN	6
TIME/MIN A	4

AVERAGE AGE	22
CORRECTION%	43
GENDER M %	57
GENDER F %	43

Table 5.9

Statistical data of cove lighting system in group 2, position 2 (See page 60).

GROUP 2
TEST 2
COVE LIGHTING

PARTICIPANT	AGE	SEX	CORRECTION	TRUE	FALSE	EMPTY	TIME(MIN)	TRUE/MIN RATIO	TRUE %
1	24	F	NO	25	0	0	3	8	100
2	24	M	NO	24	1	0	5	5	96
3	23	M	NO	23	1	1	4	6	92
4	21	M	YES	25	0	0	7	4	100
5	22	M	NO	25	0	0	7	4	100
6	24	M	YES	25	0	0	7	4	100
7	24	M	NO	23	1	1	6	4	92
8	23	M	NO	25	0	0	4	6	100
9	23	M	NO	20	2	3	5	4	80
10	20	F	NO	25	0	0	5	5	100
11	27	M	YES	25	0	0	5	5	100
12	23	F	YES	25	0	0	4	6	100
13	21	M	YES	20	3	2	6	3	80
14	25	F	YES	25	0	0	4	6	100
15	24	M	NO	25	0	0	3	8	100
16	26	M	NO	25	0	0	4	6	100
17	23	F	YES	25	0	0	7	4	100
18	23	M	NO	25	0	0	5	5	100
19	21	F	YES	25	0	0	4	6	100
20	21	F	YES	25	0	0	6	4	100
21	22	M	NO	22	3	0	6	4	88
22	25	F	NO	24	1	0	4	6	96
23	27	F	YES	23	2	0	4	6	92
24	24	F	NO	20	2	3	5	4	80
25	26	M	YES	25	0	0	8	3	100
26	25	M	NO	25	0	0	5	5	100
27	21	F	YES	21	2	2	6	4	84
28	21	F	NO	25	0	0	4	6	100
29	19	F	NO	18	6	1	5	4	72
30	21	M	NO	25	0	0	4	6	100

AVERAGE AGE	23
CORRECTION%	40
GENDER M %	57
GENDER F %	43

MIN. TIME	3
MAX. TIME	8
TIME MEAN	5
TIME/MIN A	5

TRUE MEAN	24
FALSE MEAN	1
EMPTY MEAN	0

Table 5.10

Statistical data of cove lighting system in group 1, position 3 (See page 60).

GROUP 1
TEST 3
COVE LIGHTING

PARTICIPANT	AGE	SEX	CORRECTION	TRUE	FALSE	EMPTY	TIME(MIN)	TRUE/MIN RATIO	TRUE %
1	21	F	NO	23	2	0	6	4	92
2	26	M	NO	25	0	0	4	6	100
3	24	M	YES	25	0	0	4	6	100
4	21	F	NO	25	0	0	3	8	100
5	21	F	YES	18	1	6	4	5	72
6	18	F	NO	25	0	0	4	6	100
7	23	M	NO	24	1	0	6	4	96
8	19	F	YES	25	0	0	6	4	100
9	19	F	YES	24	1	0	3	8	96
10	27	M	NO	25	0	0	6	4	100
11	21	M	NO	25	0	0	6	4	100
12	21	F	YES	25	0	0	7	4	100
13	20	F	YES	25	0	0	7	4	100
14	21	M	NO	25	0	0	5	5	100
15	26	M	NO	25	0	0	5	5	100
16	23	M	YES	22	2	1	6	4	88
17	21	F	NO	25	0	0	5	5	100
18	22	M	NO	25	0	0	7	4	100
19	21	M	YES	25	0	0	5	5	100
20	19	F	NO	25	0	0	5	5	100
21	23	F	NO	25	0	0	4	6	100
22	26	M	NO	25	0	0	5	5	100
23	26	M	YES	19	6	0	5	4	76
24	22	M	NO	24	0	1	6	4	96
25	21	M	NO	24	0	1	5	5	96
26	22	M	NO	25	0	0	5	5	100
27	25	M	NO	23	2	0	6	4	92
28	28	M	NO	25	0	0	4	6	100
29	22	F	NO	25	0	0	4	6	100
30	24	M	NO	25	0	0	4	6	100

TRUE MEAN	24
FALSE MEAN	1
EMPTY MEAN	0

MIN. TIME	3
MAX. TIME	7
TIME MEAN	5
TIME/MIN A	5

AVERAGE AGE	22
CORRECTION%	30
GENDER M %	60
GENDER F %	40

In analyzing the data considering gender, correct answer ratio, correct answer per minute ratio were computed for male and female participants for each lighting system separately. Correct answer ratios and correct answer per minute ratios were evaluated according to the sequence of each lighting system. See tables 5.11, 5.12, 5.13 for the statistical data which indicate the influences of gender on human performance under different lighting types taking their sequence into account.

The data analysis considering the correction in the eyes of the participants, correct answer ratio and correct answer per minute ratio were calculated for the participants having corrected eyes and healthy eyes for each lighting system separately. Correct answer ratios and correct answer per minute ratios were evaluated according to the sequence of each lighting system. See tables 5.14, 5.15, 5.16 for the statistical data which indicate the effects of eye correction on human performance under different lighting types considering their sequence.

After determining the correct answer ratios and correct answer per minute ratios for the three sequences of each lighting system, the overall averages of the values were computed considering gender and eye correction. For the obtained values, see tables 5.11, 5.12, 5.13, 5.14, 5.15, 5.16.

Table 5.11

Uplighting comparison table according to gender.

**GROUP 1
UPLIGHTING 1**

	MALE	FEMALE
UPLIGHTING 1	92	4
UPLIGHTING 2	90	4

**GROUP 3
UPLIGHTING 2**

	MALE	FEMALE
UPLIGHTING 2	97	5
UPLIGHTING 3	96	5

**GROUP 2
UPLIGHTING 3**

	MALE	FEMALE
UPLIGHTING 3	97	5
UPLIGHTING 4	97	6

**UPLIGHT COMPARISON TABLE
ACCORDING TO GENDER**

	MALE	FEMALE
UPLIGHTING 1	95	5
UPLIGHTING 2	94	5

Table 5.12

Wall washing comparison table according to gender.

**GROUP 2
WALL WASHING1**

	ANSWER RATE	RATIO
MALE	95	4
FEMALE	93	5

**GROUP 1
WALL WASHING2**

	ANSWER RATE	RATIO
MALE	97	5
FEMALE	96	4

**GROUP 3
WALL WASHING3**

	ANSWER RATE	RATIO
MALE	95	5
FEMALE	96	5

**WALL WASHING COMPARISON TABLE
ACCORDING TO GENDER**

	ANSWER RATE	RATIO
MALE	96	5
FEMALE	95	5

Table 5.13

Cove lighting comparison table according to gender.

**GROUP 3
COVE LIGHTING1**

	CORRECT ANSWER RATIO	CORRECT ANSWER RATIO
MALE	94	5
FEMALE	89	4

**GROUP 2
COVE LIGHTING2**

	CORRECT ANSWER RATIO	CORRECT ANSWER RATIO
MALE	96	5
FEMALE	94	5

**GROUP 1
COVE LIGHTING3**

	CORRECT ANSWER RATIO	CORRECT ANSWER RATIO
MALE	97	5
FEMALE	97	5

**COVE LIGHTING COMPARISON TABLE
ACCORDING TO GENDER**

	CORRECT ANSWER RATIO	CORRECT ANSWER RATIO
MALE	96	5
FEMALE	93	5

Table 5.14

Uplighting comparison table according to eye correction.

**GROUP 1
UPLIGHTING 1**

Correct Answer	Correct Answer Range	Correct Answer Range
88	4	
93	4	

**GROUP 3
UPLIGHTING 2**

Correct Answer	Correct Answer Range	Correct Answer Range
96	5	
97	5	

**GROUP 2
UPLIGHTING 3**

Correct Answer	Correct Answer Range	Correct Answer Range
96	5	
97	6	

**UPLIGHTING COMPARISON TABLE
ACCORDING TO EYE CORRECTION**

Correct Answer	Correct Answer Range	Correct Answer Range
93	5	
96	5	

Table 5.15

Wall washing comparison table according to eye correction.

**GROUP 2
WALL WASHING 1**

TEST POINT	TEST RESULT	CORRECTION
91	4	
93	4	

**GROUP 1
WALL WASHING 2**

TEST POINT	CORRECT ANSWER	CORRECT MARK
96	5	5
94	5	5

**GROUP 3
WALL WASHING 3**

CORRECTION	CORRECT ANSWER RATIO	CORRECT MIN RATIO
92	92	5
99	99	5

**WALL WASHING COMPARISON TABLE
ACCORDING TO EYE CORRECTION**

TEST POINT	CORRECTION: POWER RATIO	CORRECTION: VAIN POWER RATIO
14.500000000000000	93	5
14.500000000000000	95	5

Table 5.16

Cove lighting comparison table according to eye correction.

GROUP 3
COVE LIGHTING1

CORRECTION	CORRECT ANSWER RATIO	CORRECT/MIN RATIO
YES	91	4
NO	93	4

GROUP 2
COVE LIGHTING2

CORRECTION	CORRECT ANSWER RATIO	CORRECT/MIN RATIO
YES	96	5
NO	94	5

GROUP 1
COVE LIGHTING3

CORRECTION	CORRECT ANSWER RATIO	CORRECT/MIN RATIO
YES	92	5
NO	99	5

COVE LIGHTING COMPARISON TABLE
ACCORDING TO EYE CORRECTION

CORRECTION	CORRECT ANSWER RATIO	CORRECT/MIN RATIO
YES	93	5
NO	95	5

5.5. Discussion

The findings were evaluated in the frame of the tables 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 5.10. The effect of familiarity of the participants with the matching tests were observed in the context of related tables on gender and eye correction, which can be seen in tables 5.11, 5.12, 5.13, 5.14, 5.15, 5.16. However, this result was estimated prior to this assessment. In order to break this effect, the placement of the items on the matching column in each test were changed as can be seen at Appendix A, but still the effect was observed.

Different results were obtained during the comparison of the different sequences of the same lighting system in relation with gender and eye correction and the analyses are given in tables 5.11, 5.12, 5.13, 5.14, 5.15, 5.16. There was an increase in correct answer ratio and in correct answer per minute ratio for both male and female participants under uplighting and cove lighting. The analysis of the results for wall washing shows that 2% increase in correct answer ratio for only male gender was observed in the second position (See page 60) in comparison to the first position (See page 60). In the third position (See page 60), on the other hand, 2% decrease in correct answer ratio for male was observed in comparison to the second position (See page 60). For the changes in correct answer ratios and correct answer per minute ratios, see tables 5.11, 5.12, 5.13.

Comparisons among different lighting systems continued considering the eye correction effects which are given in the tables 5.14, 5.15, 5.16. Correct answer ratio of healthy eyes was 1% higher than that of corrected eyes at the second position (See page 60) of uplighting (see table 5.14) but correct answer ratio of corrected eyes was 2% higher than that of healthy eyes in the second position (See page 60) of wall washing and cove lighting (see tables 5.15, 5.16). Another assessment is that, the correct answer ratio and correct answer per minute ratio results of cove lighting and wall washing were the same for all positions.

According to the results, the first hypothesis was evaluated in terms of the mean of correct answer ratio and correct answer per minute ratio of participants according to different lighting systems. See Tables 5.17 and 5.18 for the results of this analysis. The results were analyzed for statistical significance. In other words, results of mean of correct answer ratio of the participants obtained for each lighting system were analyzed by comparing them with each other in order to understand whether the difference among them was significant or not. According to the statistical test of the first hypothesis, the mean of the results of correct answer ratio of all participants were not significantly differentiated from each other in the frame of this sample size. Therefore, the first hypothesis was rejected by the results of this statistical test. For details, see Appendix C.

Although the results were very close to each other and were rejected statistically in this sample size, it may be assumed that different results may be obtained in larger scaled studies. Furthermore, if we consider the result of correct answer ratio of wall washing, in comparison to cove lighting and uplighting (see Table 5.17), its excessive rate of 0.3% to uplighting and 0.6% to cove lighting may be a signal for providing performance increase in the long term. The average of correct answer per minute ratio for all lighting types is 5 minutes that makes no difference in terms of human performance. See Tables 5.17, and 5.18 for the mean of correct answer ratio and mean of correct answer per minute for different lighting types .

Table 5.17
Correct answer ratio mean of participants according to lighting types.

94.9	95.2	94.6

Table 5.18
Correct/min. ratio mean of participants according to lighting types.

5		5		5	

According to the results, the second hypothesis was evaluated in terms of mean of correct answer ratio of participants and correct answer per minute ratio of gender according to different lighting types. See Table 5.19 for the results. The results were analyzed for statistical significance. Results of mean of correct answer ratio considering gender according to different lighting types were analyzed by comparing the results of male and female participants. According to the statistical test of the second hypothesis, the mean of the results of correct answer ratio for males and females were not significantly differentiated from each other in the frame of this sample size. Consequently, the second hypothesis was rejected by the results of this statistical test. For details, see Appendix C.

The observations in the frame of Table 5.19 are as follows; according to correct answer ratio, males were 1% higher than females in wall washing, males were 1% higher than females in uplighting, males were 3% higher than females in cove lighting. The correct answer per minute ratio was the same for both gender under all lighting systems. See Table 5.19 for statistical analysis, and see Appendix B for charts.

Table 5.19
Correct answer and correct answer/min ratio of gender according to lighting types.

	Wall Washing		Uplighting		Cove Lighting	
	Correct Answer Ratio	Correct Answer/Min	Correct Answer Ratio	Correct Answer/Min	Correct Answer Ratio	Correct Answer/Min
Male	95	5	96	5	96	5
Female	94	5	95	5	93	5

According to the results, the third hypothesis was evaluated in terms of the mean of correct answer ratio of participants and correct answer per minute ratio, considering eye correction according to different lighting systems. See Table 5.20 for the results. The results were analyzed for statistical significance. Results of the mean of correct answer ratio for eye correction according to different lighting types were analyzed by comparing corrected and healthy eye ratio under different lighting types. According to the statistical test of the third hypothesis, the mean of the results of correct answer ratio of eye correction and that of healthy eye were not significantly differentiated from each other in the frame of this sample size. Consequently, the third hypothesis is supported by the results of this statistical test. For details see Appendix C.

In the third hypothesis, the correction in eye was considered as the eye deficiency which was corrected by an instrument like contact lens or glasses, so it was accepted that the eye can see properly as a healthy eye. The observations in the frame of Table 5.20 are as follows; according to correct answer ratio of participants having healthy eyes and corrected eyes, the healthy eye has an excessive rate of 2% in wall washing, 3% in uplighting, 2% in cove lighting than the corrected eye. The correct answer per minute ratio is the same for both eye situations under all lighting types. See Table 5.20 for statistical analysis, and see Appendix B for charts.

Table 5.20

Correct answer and correct answer/min ratio of eye correction according to lighting types.

	93	5	93	5	93	5
	96	5	95	5	95	5

In addition to the mentioned factors above, the effects of culture, education, race, ethnics, cultural background and geographical factors, have to be analyzed as complementary factors. In spite of knowing the importance of these factors, the effects of them on performance were not analyzed in depth due to time limitation and difficulty of finding samples from different races and ethnics in the Bilkent University. The samples were chosen among the undergraduate students of Bilkent University, Department of Interior Architecture and Environmental Design of the Faculty of Art, Design and Architecture, who were from different geographical regions, having different cultural backgrounds.

In addition, concerning the performance, the psychological situation such as the mood of the samples, and the timing of the test hours may play an important role on the concentration of the samples. But these factors may carry the study to a larger context than lighting.

5. CONCLUSION

Smith and Rea (29), in their works on reading test, claimed that added increments of light improve the performance of the reader. This current work puts forward another approach by studying the effects of different lighting types on human performance. Considering Table 5.17; it may be concluded that in addition to other performance requirements some changes on lighting systems in favor of wall washing may lead to an increase in performance in working places.

Veitch and Newsham (3-13) made typing and proofreading tests under different types of lighting and luminaries like lensed and louvered, direct and indirect systems. They also searched the highest speed and lowest error rate under different lighting conditions in office environments. They found that some lighting systems effect the human speed and error rate, which mean the performance of the worker. Although the results of this study have not proved significant differentiations in the frame of its sample scale, there are some minor indications parallel to the assessments of Veitch and Newsham.

Yucetas (56) states that there is no relation between gender differences and perception of the space. This study was also conducted in the room FC 112 which was the room used by Yucetas for her study in 1997. The results of

Table 5.19 and results of Yucetas's work about gender are supporting each other.

Lighting is a very important ingredient of interior environments. Lighting has numerous effects on humans and human performance. It can hinder or improve performance. While having rapid developments in lighting industry the significant increases in energy consumption should be considered in the context of global economic problems. And, the researchers should devote their efforts to develop the most effective and efficient lighting systems.

This study aimed to find out whether there is a relationship between types of lighting and human performance or not. It was also tried to find out the most favourable lighting type among wall washing, cove lighting and uplighting. It was concluded by a very minor significance in favour of wall washing in terms of performance. Also gender and eye corrections had no effects on human performance under different lighting conditions in this sample scale.

The participants were from Department of Interior Architecture and Environmental Design. They were almost at the same age and were in the young age group. Further step of this study may be to renewal it with a large range of age groups by considering other performance related factors such as culture, education, races, ethnics, different cultural backgrounds and different geographical factors and psychological aspects, etc.

Another further step may be to work on this subject in cooperation with different illuminance values. Effectiveness and energy consumption have great importance in recent years. Also energy is a very valuable and expensive resource. Several works on the different types of lighting with the different illuminance values may give some results that will support the energy efficiency and may increase performance at the same time. Besides, providing the proper and comfortable lighting for people at work must be an ultimate aim of this modern working life.

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APPENDICES

APPENDIX A

Table 5.21

Test No 1, used for all groups in position 1.

<u>I</u>	<u>II</u>
A. PB596	<input type="checkbox"/> PB699
B. BP996	<input type="checkbox"/> BP656
C. PB956	<input type="checkbox"/> PB556
D. BP669	<input type="checkbox"/> BP559
E. PB566	<input type="checkbox"/> PB966
F. PB569	<input type="checkbox"/> BP965
G. PB966	<input type="checkbox"/> BP596
H. BP956	<input type="checkbox"/> BP569
I. PB659	<input type="checkbox"/> BP566
J. BP656	<input type="checkbox"/> PB566
K. BP695	<input type="checkbox"/> PB659
L. BP559	<input type="checkbox"/> PB595
M. PB695	<input type="checkbox"/> BP996
N. PB699	<input type="checkbox"/> PB656
P. BP596	<input type="checkbox"/> BP659
Q. PB556	<input type="checkbox"/> PB596
R. PB655	<input type="checkbox"/> PB965
S. BP965	<input type="checkbox"/> BP655
T. BP566	<input type="checkbox"/> PB655
U. PB656	<input type="checkbox"/> PB569
V. BP569	<input type="checkbox"/> PB956
W. BP659	<input type="checkbox"/> BP695
X. BP655	<input type="checkbox"/> BP956
Y. PB595	<input type="checkbox"/> PB695
Z. PB965	<input type="checkbox"/> BP669

Table 5.22

Test No. 2. used for all groups in position 2.

	<u>I</u>	<u>II</u>
A.	PB596	<input type="checkbox"/> PB556
B.	BP996	<input type="checkbox"/> PB566
C.	PB956	<input type="checkbox"/> BP656
D.	BP669	<input type="checkbox"/> PB695
E.	PB566	<input type="checkbox"/> BP559
F.	PB569	<input type="checkbox"/> BP659
G.	PB966	<input type="checkbox"/> BP566
H.	BP956	<input type="checkbox"/> PB595
I.	PB659	<input type="checkbox"/> BP996
J.	BP656	<input type="checkbox"/> PB656
K.	BP695	<input type="checkbox"/> BP965
L.	BP559	<input type="checkbox"/> PB659
M.	PB695	<input type="checkbox"/> BP669
N.	PB699	<input type="checkbox"/> PB655
P.	BP596	<input type="checkbox"/> BP655
Q.	PB556	<input type="checkbox"/> PB956
R.	PB655	<input type="checkbox"/> BP569
S.	BP965	<input type="checkbox"/> PB966
T.	BP566	<input type="checkbox"/> PB965
U.	PB656	<input type="checkbox"/> BP695
V.	BP569	<input type="checkbox"/> PB699
W.	BP659	<input type="checkbox"/> PB596
X.	BP655	<input type="checkbox"/> PB569
Y.	PB595	<input type="checkbox"/> BP956
Z.	PB965	<input type="checkbox"/> BP596

Table 5.23

Test No. 3, used for all groups in position 3.

<u>I</u>		<u>II</u>	
A.	PB596	<input type="checkbox"/>	BP659
B.	BP996	<input type="checkbox"/>	BP956
C.	PB956	<input type="checkbox"/>	BP566
D.	BP669	<input type="checkbox"/>	PB655
E.	PB566	<input type="checkbox"/>	PB965
F.	PB569	<input type="checkbox"/>	PB695
G.	PB966	<input type="checkbox"/>	BP656
H.	BP956	<input type="checkbox"/>	BP596
I.	PB659	<input type="checkbox"/>	PB956
J.	BP656	<input type="checkbox"/>	BP569
K.	BP695	<input type="checkbox"/>	PB566
L.	BP559	<input type="checkbox"/>	BP996
M.	PB695	<input type="checkbox"/>	PB595
N.	PB699	<input type="checkbox"/>	PB659
P.	BP596	<input type="checkbox"/>	PB966
Q.	PB556	<input type="checkbox"/>	BP669
R.	PB655	<input type="checkbox"/>	BP655
S.	BP965	<input type="checkbox"/>	BP695
T.	BP566	<input type="checkbox"/>	PB569
U.	PB656	<input type="checkbox"/>	PB556
V.	BP569	<input type="checkbox"/>	PB596
W.	BP659	<input type="checkbox"/>	BP965
X.	BP655	<input type="checkbox"/>	BP559
Y.	PB595	<input type="checkbox"/>	PB699
Z.	PB965	<input type="checkbox"/>	PB656

APPENDIX B

Table 5.24

Correct Answer Ratio of gender according to lighting types.

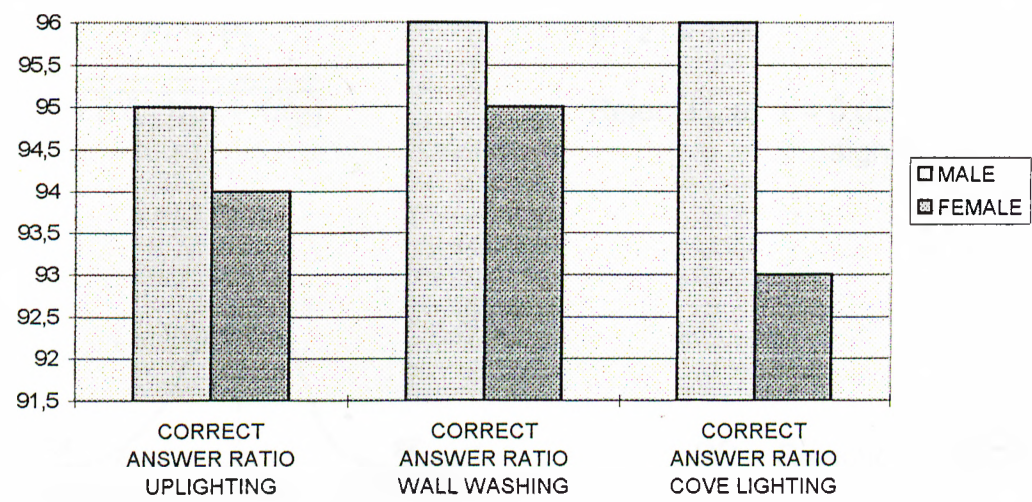
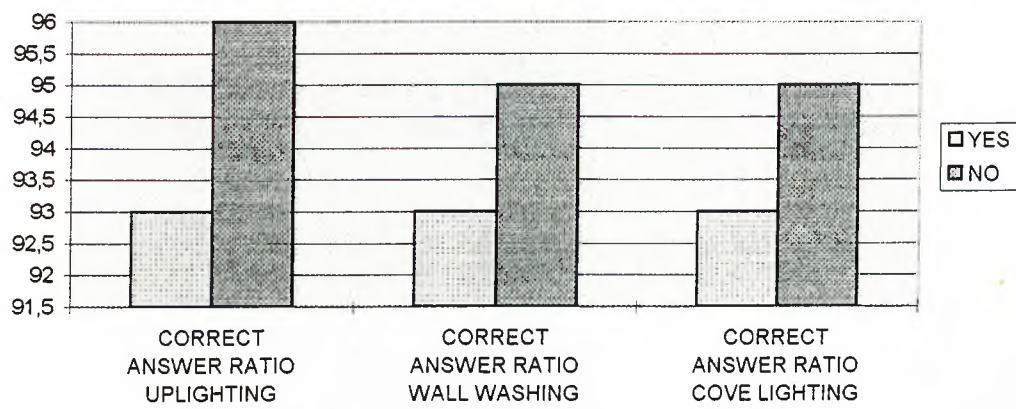


Table 5.25

Correct Answer Ratio of eye correction according to lighting types.



APPENDIX C

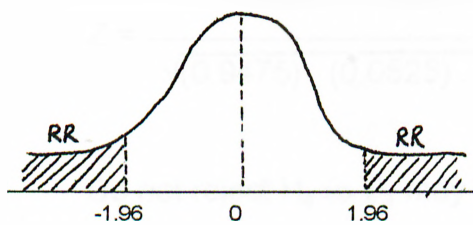
Statistic test for significant difference.

Standard Normally Distributed Test.

$$Z = \frac{\hat{P}_1 - \hat{P}_2}{\sqrt{\bar{p}\bar{q}(1/n_1 + 1/n_2)}}$$

If $|z| > 1.96$

Reject H_0 at $\alpha = 0.05$ level of significance



RR = Rejection Region

Statistical testing for Hypothesis 1

<u>1</u>	<u>2</u>	<u>3</u>
UPLIGHTING	WALL WASHING	COVE LIGHTING
94.9	95.2	94.6

a) $H_0 : P_1 = P_2$
 $H_a : P_1 \neq P_2$

b) $H_0 : P_1 = P_3$
 $H_a : P_1 \neq P_3$

c) $H_0 : P_2 = P_3$
 $H_a : P_2 \neq P_3$

a) $\bar{p} = 0.949 + 0.952 / 2 = 0.9505$ $\bar{q} = 1 - \bar{p}$

$$Z = \frac{0.949 - 0.952}{\sqrt{(0.949) \cdot (0.0495) \cdot (1/90 + 1/90)}} \cong -0.0928$$

Do not reject $H_0 \Rightarrow P_1$ may be equal to P_2 .

b) $\bar{p} = 0.949 + 0.946 / 2 = 0.9475 \Rightarrow \bar{q} = 0.0525$

$$Z = \frac{(0.949 - 0.946) - 0}{\sqrt{(0.9475) \cdot (0.0525) \cdot (1/90 + 1/90)}} \cong 0.09023$$

Do not reject $H_0 \Rightarrow P_1$ may be equal to P_3 .

c) $\bar{p} = 0.952 + 0.946 / 2 = 0.949 \Rightarrow \bar{q} = 0.051$

$$Z = \frac{(0.952 - 0.946) - 0}{\sqrt{(0.949) \cdot (0.051) \cdot (1/90 + 1/90)}} \cong 0.183$$

Do not reject $H_0 \Rightarrow P_2$ may be equal to P_3 .

There seems to be no significant difference in the proportion of correct answers under different lighting conditions.

Statistical testing for Hypothesis 2

	a		b		c	
	UPLIGHTING		WALL WASHING		COVER LIGHTING	
	CORRECT ANSWER RATIO	TRUE PM RATIO	CORRECT ANSWER RATIO	TRUE PM RATIO	CORRECT ANSWER RATIO	TRUE PM RATIO
MALE	95	5	96	5	96	5
FEMALE	94	5	95	5	93	5

a) Uplighting

$$H_0 : P_M = P_F$$

$$H_a : P_M \neq P_F$$

P_M = Correct Answer Ratio for male.
 P_F = Correct Answer Ratio for female.

$$n_M = 52, \hat{P}_M = 0.95$$

$$n_F = 38, \hat{P}_F = 0.94$$

$$\bar{p} = 0.945$$

$$\bar{q} = 0.055$$

$$Z = \frac{(0.95 - 0.94) - 0}{\sqrt{(0.945) \cdot (0.055) \cdot (1/52 + 1/38)}} \approx 0.2055$$

Do not reject $H_0 \Rightarrow P_M$ may be equal to P_F .

b) Wall Washing

$$H_0 : P_M = P_F$$

$$H_a : P_M \neq P_F$$

P_M = Correct Answer Ratio for male.
 P_F = Correct Answer Ratio for female.

$$n_M = 52, \hat{P}_M = 0.96$$

$$n_F = 38, \hat{P}_F = 0.95$$

$$\bar{p} = 0.955$$

$$\bar{q} = 0.045$$

$$Z = \frac{(0.96 - 0.95) - 0}{\sqrt{(0.955) \cdot (0.045) \cdot (1/52 + 1/38)}} \cong 0.226$$

Do not reject $H_0 \Rightarrow P_M$ may be equal to P_F .

c) Uplighting

$$H_0 : P_M = P_F$$

$$H_a : P_M \neq P_F$$

P_M = Correct Answer Ratio for male.

P_F = Correct Answer Ratio for female.

$$n_M = 52, \hat{P}_M = 0.96$$

$$n_F = 38, \hat{P}_F = 0.93$$

$$\bar{p} = 0.945$$

$$\bar{q} = 0.055$$

$$Z = \frac{(0.96 - 0.93) - 0}{\sqrt{(0.945) \cdot (0.055) \cdot (1/52 + 1/38)}} \cong 0.6166$$

Do not reject $H_0 \Rightarrow P_M$ may be equal to P_F .

Statistical testing for Hypothesis 3

	UPLIGHTING		WALL WASHING		CONE LIGHTING	
	CORRECT ANSWER RATIO	TRIALS	CORRECT ANSWER RATIO	TRIALS	CORRECT ANSWER RATIO	TRIALS
MALE	93	5	93	5	93	5
FEMALE	96	5	95	5	95	5

a) Under Uplighting

$$H_o : P_Y = P_N$$

$$H_a : P_Y \neq P_N$$

P_Y = Proportion of correct answers (Corrected eyes)

P_N = Proportion of correct answers (Healty eyes)

$$\hat{P}_Y = 0.93, n_Y = 37$$

$$\hat{P}_N = 0.96, n_N = 53$$

$$\bar{p} = 0.945$$

$$\bar{q} = 0.055$$

$$Z = \frac{0.93 - 0.96}{\sqrt{(0.945) \cdot (0.055) \cdot (1/53 + 1/37)}} \cong -0.614$$

Do not reject $H_o \Rightarrow P_Y$ may be equal to P_N .

b) Under Wall Washing

$$H_o : P_Y = P_N$$

$$H_a : P_Y \neq P_N$$

P_Y = Proportion of correct answers (Corrected eyes)

P_N = Proportion of correct answers (Healty eyes)

$$\hat{P}_Y = 0.93, n_Y = 37$$

$$\hat{P}_N = 0.95, n_N = 53$$

$$\bar{p} = 0.94$$

$$\bar{q} = 0.06$$

$$Z = \frac{0.93 - 0.95}{\sqrt{(0.94) \cdot (0.06) \cdot (1/53 + 1/37)}} = -0.3931$$

Do not reject $H_o \Rightarrow P_Y$ may be equal to P_N .

c) Under Cove Lighting

$$H_0 : P_Y = P_N$$

$$H_a : P_Y \neq P_N$$

P_Y = Proportion of correct answers (Corrected eyes)

P_N = Proportion of correct answers (Healty eyes)

$$\hat{P}_Y = 0.93, n_Y = 37$$

$$\hat{P}_N = 0.95, n_N = 53$$

$$\bar{p} = 0.94$$

$$\bar{q} = 0.06$$

$$Z = \frac{0.93 - 0.95}{\sqrt{(0.94) \cdot (0.06) \cdot (1/53 + 1/37)}} = -0.3931$$

Do not reject $H_0 \Rightarrow P_Y$ may be equal to P_N .

Eye correction may make no difference under different lighting conditions.